FODDER OATS: a world overview

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FODDER OATS:
a world overview

Edited by

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CONTENTS

FOREWORD

FAO has long emphasized the importance of fodder crops and their role in farming systems, particularly for smallholders. Oats are one such fodder crop that has gained in importance in recent years, particularly with the availability of new cultivars and multicut varieties. Although the overall area sown to oats has fallen over the past century, partly due to the decline in the number of draught and cavalry horses, for which oats were the basic feed grain, they have become increasingly important as green and conserved fodder, both in temperate and many subtropical areas.

Information on fodder oats, and particularly on the considerable changes that have taken place in the last twenty years, especially in terms of their growing importance as a winter fodder and the increasing areas under fodder oats, is scattered in various publications or is not readily available. This book brings together information on the state of fodder oats worldwide, and is aimed mainly at agronomists and extension workers. While the book considers oats in large-scale production systems, particular emphasis has been given to the smallholder sector and to the increasingly important role of oats in smallholder production systems.

FAO has focused on oats in the Maghreb countries through an Oat-Vetch Network, and in the Himalaya-Hindu Kush, in particular, has emphasized the important role of oats in smallholder production systems. The Fifth Meeting of the Temperate Asia Pasture Working Group, in Bhutan in 2002, discussed *Fodder Oats – a forage crop for mountain areas* and subsequently, through a Fodder Oat Network, initiated activities to evaluate new oat cultivars, exchange information and ensure that promising new oat germplasm is made available to smallholders, and particularly those involved in dairying. Several papers from that meeting have been included in this book. With papers from North America, South America, Europe and Australasia, and country or regional studies from the Maghreb, the Himalaya, Pakistan, China and Japan, the book brings together information from all regions of the world from contributing authors who are all regional experts in their field.

The contributions of authors are much appreciated by FAO in its efforts to disseminate information on fodder production, particularly for the smallholder sector. The considerable input made by the editors – retired staff member James Suttie, and Stephen Reynolds of the Grassland and Pasture Crops Group of the Crop and Grassland Service – both for their personal contributions and in ensuring that the book was brought to publication, is particularly acknowledged.

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ACRONYMS

ADF	acid detergent fibre
AJK	Azad Jammu and Kashmir
BYDV	Barley Yellow Dwarf Virus
CCN	Cereal cyst nematode
CFR	Crop and Food Research Limited
CGIAR	Consultative Group on International Agricultural Research
CTK	C-terminal kinase
CIMMYT	Centro Internacional para el Mejoramiento del Maíz y del Trigo/ International Maize and Wheat Improvement Center
DSIR	Department of Scientific and Industrial Research
FYM	farmyard manure
GRDC	Grains Research and Development Corporation
HHK	Himalaya-Hindu Kush
ICARDA	International Center for Agricultural Research in the Dry Areas
IGFRI	Indian Grassland and Fodder Research Institute
IAA	Indole-3-acetic acid
INIA	Instituto Nacional de Investigaciones Agropecuarias
INRAT	Institut National de la Recherche Agronomique de Tunisie
INTA	Instituto Nacional de Tecnología Agropecuaria
IVDDM	*in vitro* digestible dry matter
MADREF	Ministère de l'Agriculture et Développement Rural et des Eaux et Forêts [Morocco]
MS	Murashige and Skoog
NARC	National Agricultural Research Centre
NCRCP	National Cereal Rust Control Programme
NDF	neutral detergent fibre
NGO	non-governmental organization
NSW	New South Wales
NWFP	North West Frontier Province
PBR	Plant Breeders Rights
QION	Quaker International Oat Nursery
TDN	total digestible nutrients
TNC	total non-structural carbohydrates
UFRGS	Federal University of Rio Grande do Sul [Brazil]
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WSC	water-soluble carbohydrate
WTO	World Trade Organization

Chapter I
Background to fodder oats worldwide

INTRODUCTION

Oats are a crop of Mediterranean origin; not as old as wheat and barley, but their domestication dates back to ancient times. They have many uses: a cereal, a feed grain, green or conserved fodder and, more recently, as a winter cover crop in no-till rotations. Recent changes in farming systems as well as the availability of new cultivars better suited to grazing and mowing have altered the distribution of oats as a fodder: their use may have lessened in some temperate areas, but has greatly increased in many subtropical zones, in both smallholder and mechanized farming systems where previously they were little used. Oats are finding new uses and farmers and researchers are finding ways of integrating them into their production systems wherever they are economically interesting. This book deals with the whole green oat crop used as fodder (whether fed fresh or conserved) and emphasizes their increasing use in smallholder production systems. Oats as a cereal is dealt with in great detail by Welch (1995).

This publication aims to bring together information on fodder oats from all regions of the world; its contributing authors are all regional experts in their field. Much of the Asian work consolidates FAO-supported work carried out in recent years in smallholder farming areas. One chapter is devoted to a worldwide overview of fodder oats; thereafter there are chapters by continent for North America, South America, Europe and Australasia, and country or regional studies from the Maghreb, the Himalaya, Pakistan, China and Japan. A chapter on diseases follows, and the final chapter discusses perspectives for fodder oats.

The genus *Avena* comprises about seventy species; a few are cultivated. *Avena sativa* L. (Figures 1.1a, b & c) and *Avena byzantina* K. Koch sometimes known as the white oat and red oat, respectively, are the main oats grown for fodder and grain. They are hexaploids and modern cultivars may contain genetic material from both species. *Avena strigosa*, the bristle-pointed oat or black oat, is a diploid. Until recently it was a minor crop of poor soils and harsh climates in parts of Eastern Europe, Wales and some Scottish islands. Recently, *A. strigosa* has become very important in subtropical and temperate situations as a winter cover crop and forage, as described in Chapter IV. Oats are well suited for use as cover or break crops in winter rotations since they are not susceptible to the major root diseases of wheat and barley; they have a high reputation for weed control, partly due to their high biomass production, but this may be enhanced by allelopathy.

Naked types occur in several species: *Avena sativa* (6n=42) is the naked oats used in commerce, conspecific with the domestic covered oat. The diploid *A. strigosa* Schreb. (2n=14) is hulled, but also has a naked type. There is also a diploid naked oat, *A. nuda* L. (2n=14), but it is not commonly cultivated. Naked oats are a minor crop, notably grown at high altitudes in China. There

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Figure 1.1a
*Cultivated oats (*Avena sativa *L.) at different growth stages: (a) boot stage*

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Figure 1.1b
*Cultivated oats (*Avena sativa *L.) at different growth stages: (b) head emergence*

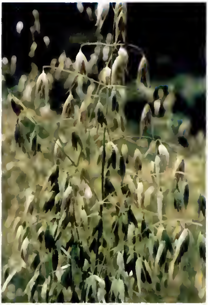

Figure 1.1c
Cultivated oats (Avena sativa L.) at different growth stages: (c) grain filling stage

has been increasing interest in the crop recently as the hull-free grain has a higher energy concentration than common oats. Free-threshing is not an important characteristic for green fodder production, and the naked quality is unimportant for this purpose. Information on areas sown is scarce, but Hu and Zhang (2003) give the area in China of naked oats in 1998 at 118 700 ha, compared with 155 700 ha for *A. sativa*.

THE OAT CROP

The area sown to oats has fallen sharply over the past century; part of this is due to the replacement of draught horses in the farming systems in the developed world and in haulage – oats were the basic feed of work horses in many places. While the area under white-straw crops worldwide differs little from that of forty years ago (Figure 1.2), the area under oats has fallen steadily and in 2000 was but a third of that of 1961; in contrast, barley is currently at its 1961 level, after a rise between 1970 and 1990.

The areas reported in the FAOSTAT database, however, do not always agree with those cited by some of the authors in this book nor with obvious increases in fodder oats in the field: they probably reflect the areas grown for grain. Where oats are grown to be harvested as whole green crop they may be ignored in statistics, or lumped with forages where such statistics are kept.

Great changes have taken place in the areas where fodder oats are important. Oats are now a very important winter fodder on small farms in Pakistan and northern India; some of this is described in Dost (2001, 2002, 2003). In the Himalayan zone – often in association with dairying – oats have changed from a minor fodder to a major crop in the past twenty years, mainly because of the availability of improved cultivars and their ability to produce green feed during the midwinter lean period. There has been a vast increase in the use of oats (mostly *A. strigosa*) as a winter cover crop-cum-fodder in the southern cone of South America in recent years; this is described in detail in Chapter IV. The areas given in FAOSTAT for the Southern Cone countries for 2003 are: Argentina, 300 665 ha; Brazil, 267 652 ha; Chile, 104 620 ha; and Uruguay, 50 000 ha. Federizzi and Mundstock, in Chapter IV of this book,

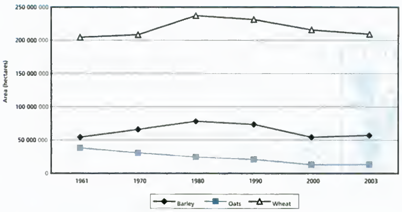

Figure 1.2
World areas of white straw crops
Source: FAOSTAT database.

indicate that over 2 million hectares of oats are currently grown in Argentina and Uruguay, and over 3 million hectares in Brazil. Oats have become an important fodder in Pakistan over the past twenty years; this is described in Chapter VI and is very obvious throughout Punjab in late winter through to spring, yet no oats are reported in FAOSTAT for that or any of the neighbouring countries.

The cultivation of oats follows the general methods for wheat and barley, and similar equipment can be used. There are, however, many ways of growing these crops and some are described in the following chapters. A great range of methods are described, from simple manual techniques to highly mechanized systems. Basic techniques, such as seedbed preparation and seed rates, vary widely. No attempt is made to synthesize these methods: each region and system has to develop its own systems. However, the use of adapted cultivars, resistant to the main diseases and suitable for forage use, is common to all oat growing.

OATS AS FODDER

Whole-crop green oats may be grazed, cut-and-carried, ensiled or made into hay. In some situations, especially with multicut varieties, the crop may be lightly grazed before stem elongation (*déprimage* in French; there seems to be no English equivalent), allowing the crop to recover and produce a further forage crop, or grain for harvest. The suitability of grazing as a method of exploitation depends on the weather and soil conditions; oats do not recover well from heavy grazing and, where a second cut is desired, grazing must be careful or light. Multiple cutting is highly productive, especially manually – as in smallholder systems – and recently developed cultivars are better suited to such management.

Much of the breeding emphasis is on increased grain production, and disease issues. Crown rust and stem rust are important problems requiring attention, and especially for forage purposes. Oats for forage accentuate the problems of rust because oat crops for grain have very clearly defined seasons, limiting the spread of rust, but oats for forage can be grown outside normal or traditional seasonal timeframes, creating what some call the "green bridge" – continuous green forage crops on which the rust inoculum can survive year round. There is great variation in green forage production yields between cultivars, and this can be easily measured. The various traits of thin leaves or wide leaves are not that significant insofar as yield goes, but may used by companies as marketing themes to highlight differences between competing cultivars. It is better to focus scarce breeding resources on disease screening, which is what most breeders do. Rust is the biggest single factor affecting yield and quality in areas where forage breeding is current: South America, Australasia and North America.

Yield is what the farmers require, although the cultivars being released have attracted interest not only for their higher yield but also for their wide leaves, later maturity and compact head type. Farmers often associate these traits with increased yield, but there are no direct linkages. Maturity can be important, particularly at lower latitudes where day length influences on growth rates in winter are minimal. However, if used for seed production at these lower latitudes, grain production may not be possible because of this late plant maturity characteristic.

Early biomass production is important. Uusually, the sooner the farmer can graze the crops, the better. Vegetative recovery in grazing systems is not oats' strong point in the colder environments, but improves according to winter temperatures. For example, more grazings are possible in Queensland than in Southern Australia, or in North Island, New Zealand, than in South Island. However, under cut-and-carry systems, where oat forage is cut to a controlled depth, vegetative recovery improves dramatically. Vegetative recovery from grazing in cooler winter environments requires additional breeding attention, which is ongoing in New Zealand, using different germplasm. This characteristic receives little attention from plant breeders, but it should be remembered that few plant breeders work on fodder oats.

There has been greatly increased interest in fodder oats in several subtropical situations where previously the crop was unimportant. In smallholder systems, especially where systems involve peri-urban dairying, this is most evident in the northern parts of southeast Asia. Oats are well suited to cultivation by smallholders as oats can be grown and harvested with the same simple equipment that is used for rice and wheat, the two main staples in most systems where oats have become popular; seedbed preparation and sowing are uncomplicated. Seed is easily produced, so farmers do not have to buy often, and farmer-to-farmer sales have greatly accelerated the spread of improved cultivars. Oats are largely self-pollinated so farmers can save their own seed for several crops, provided that rogueing is carried out and the usual precautions are taken against mechanical contamination. Green feed can be cut as required, using a sickle, the tool used for wheat and

rice harvest. There is also a great increase in oat cultivation in mainly large-scale mechanized systems in South America, both for fodder and as a winter cover.

In some areas where they have been a traditional fodder, green oats have decreased sharply in importance. These include two major situations: in areas of mechanized farming and intensive stock-raising with hot summers maize, is a much easier crop to conserve (as silage) and generally provides a feed of higher energy content; in moist, cooler temperate climates, short rotation pastures based on ryegrasses are now preferred for ensiling.

Oats can be made into good hay in areas with dry, warm conditions at harvest time but, because of their coarser stems, they are less easy to cure than pasture grasses and less suitable for hay in cooler climates. Oat hay is traded, sometimes internationally. Chapter X indicates that specialist cultivars for hay production are being developed to meet export quality specifications for Australia's growing oaten hay export trade to southeast Asia. Oats are easy to ensile, although their hollow stems require short chopping and good compaction. Oat straw is a good, palatable roughage and is also excellent bedding. Haymaking and the conservation of straw are dealt with in detail in another recent FAO publication (Suttie, 2000a).

Some "wild" species of *Avena* have excellent fodder characteristics and figure largely in the composition of the fallow *bour* phase of traditional cereal-fallow rotations in the rainfed cropping areas of North Africa and western Asia. *A. fatua* and *A. ludoviciana* (syn. *A. sterilis*), the "winter wild oat", are excellent natural grazing; unfortunately they are very serious weeds of wheat and barley. Wild oats are notorious throughout wheat and barley growing areas – they are known and detested in areas where cultivated oats are unknown; this can cause resistance to the introduction of fodder oats in traditional wheat growing areas. Oats have been spectacularly successful in Pakistan, and there are many agro-ecological zones in neighbouring Afghanistan where they suit the needs of dairy farmers. The first attempts to introduce fodder oats to lowland Afghanistan by the FAO agricultural rehabilitation programme brought strong objections from the rural population. There is, however, a lot of contact between farmers in these neighbouring countries and now oats are being grown in suitable "dairy pockets" in Afghanistan.

OAT GRAIN

The main use of oat grain is as animal feed, alone or in mixture; much is used on-farm. The traditional preparation of oats for human consumption is more laborious than that of wheat since the grain has to be milled to remove the glumes, often after kiln-drying; then winnowed to obtain the "groats", which are the edible huskless grain, before any further milling or preparation. Oatmeal and oat-flour are not suitable for bread making but are consumed traditionally as porridge or hard, flat cakes, or added to other dishes as a thickening. Nowadays, the main use of oats as human food is in breakfast cereals. Oatmeal, once the main staple in Scotland, came in for very strong competition from imported wheat from the mid-nineteenth century: Smout (1988) reports "Between 1857 and 1903 the price of a sack of 280 lb of oatmeal fell only slightly, from 37 shillings to 31 shillings; while the price of the same quantity of wheat dropped from 46 shillings

to 22 shillings ... The consequence was that many poor families shifted from porridge to white bread and tea." Those interested in traditional oatmeal dishes should read MacNeill (1929) and Lockhart (1997).

THE BOOK

This book aims to bring together information on the state of fodder oats worldwide and is aimed mainly at agronomists and extension workers. Since oats are an excellent fodder on small farms in suitable climates, particular attention has been given to countries where fodder oats are, or are becoming, important in the smallholder sector.

Chapter II, which was originally the theme paper for the Fifth Meeting of the Temperate Asia Pasture Working Group, held at Wangdue, Bhutan, in 2002, provides an overview of fodder oats in a general context, as well as a specific focus on the Himalaya-Hindu Kush region and the proposal for a Fodder Oat Network. Chapter III gives an overview of fodder oats in North America, where oats are still very important, although their range has been reduced by other fodders and they are now mainly a summer crop on the Northern Great Plains and a winter crop in milder climates.

Chapter IV covers South America, where the use of oats as a fodder and winter cover crop has increased very greatly in recent years. Oats are grown in five major environments: the temperate area of Argentina and Uruguay; the temperate area of Chile; the subtropical area of Brazil (south of 24°S); the tropical area of Brazil (north of 24°S); and the tropical high altitude area (parts of the highlands of Bolivia, Ecuador and Peru). The largest area under oats is in temperate and subtropical regions, but oats as a grain crop are increasing in area and importance in all environments of South America. The cropped area is increasing every year because it is a major component in the rotation system used by farmers when they adopt the no-till system. In some parts of the region, oat-growing areas are not always currently animal production zones, and there may be great potential for more integration of the two enterprises.

In Africa, the main area of production – almost entirely for hay and grazing – is in the Mediterranean climate of Northwest Africa – the Maghreb – and Chapter V describes the present situation in Algeria, the Libyan Arab Jamahiriya, Morocco and Tunisia. Outside the Mediterranean basin, oats, in Africa, are a traditional crop only in Ethiopia, where the area has grown from 10 000 ha in 1961 to 42 000 ha in 2003 (FAOSTAT data). They can be grown at higher altitudes in the tropical and equatorial zones, and were an important fodder in the higher areas of Kenya, but the area sown dropped very sharply between 1960 and 1970, from 11 331 ha to 5 000 ha, partly because of changes in farming systems and holding size. According to Boonman (1993), discussing Kenya: "Oats owe their reputation to their versatility as they grow well from 1 750 – 3 000 m for grain, hay and grazing. At lower altitudes oats are less suitable as tillering is limited and no dense canopy is formed. Farmers are better off with grass sorghum as fodder-, break- or catch-crops." The main varieties in use in Kenya were Suregrain, Lampton and Grey Algerian, the last-named being a popular porridge oat. South Africa still has an appreciable area, 25 000 ha, down from 80 000 ha in 1970 (FAOSTAT data).

Chapters VI and VII present case studies from Pakistan, India, Bhutan and Nepal, mostly provided through the FAO-assisted Temperate Asia Pasture Working Group. Fodder is grown on a large scale throughout the subregion, by both stock owners and specialist fodder producers, mainly for dairying; the main fodder, *Trifolium alexandrinum*, hardly grows from mid-December until early February – a period when oats remain productive. The multicut qualities of new cultivars can have their full expression under the prevailing system of hand-cutting and carrying the crop to the stock; grazing can cause heavy damage to oats, even when carefully done, especially on wet or light soils. Since the introduction of multicut fodder cultivars in the 1980s, the area under oats has increased rapidly on the northern plains of India and Pakistan, as well as in the Himalaya-Hindu Kush region. This has been encouraged by the increased profitability of peri-urban dairying and the fact that oats provide fodder at a season when most others crops are dormant. Oats have also increased as they are eminently suitable for haymaking under the hot, dry conditions prevailing at harvest time. The increase in fodder marketing to peri-urban dairies is described in detail by Dost (2003) and in Suttie (2000b). Case Studies are presented from Bhutan, China, India, Nepal and Pakistan. The major producer of oats in southeast Asia is, of course, China; the only other southeast Asian country featuring in FAOSTAT for oats is the Democratic People's Republic of Korea, with 7 000 ha, down from 56 000 ha in 1970. Mongolia grew a considerable area of fodder oats during the collective period, with about 50 000 ha in the 1970s and 1980s, falling to 30 000 ha in 1990 at decollectivization, and now, with the collapse of the arable sector, the crop has disappeared.

Chapters VIII and IX deal with China and Japan. China has always been a large grower of oats and the naked form of *A. sativa* has been grown there for centuries. The area sown to oats has fallen sharply with the replacement of draught and army horses by machines, and a reduction in the use of naked oats as a subsistence food. Forage oats, however, are still very important, both in areas too cool for maize and other hot-season fodders, and as a winter fodder in mild areas. Imported, hulled cultivars have replaced naked oats as a fodder crop. Oat breeding is active. Oats are a recent (late nineteenth century) introduction to Japanese agriculture and their use as a cereal has dropped sharply, but they are still an important fodder.

Chapter X discusses Australasia. Oat fodder crop production occurs mainly in the southern agricultural regions of both New Zealand and Australia, but grazing areas are expanding in subtropical Queensland and the temperate North Island of New Zealand. In recent years, the New Zealand oat industry has moved away from the use of dual-purpose cultivars toward specialist oat cultivars bred for forage use. This move has been driven by an expanding dairy industry, intensification of livestock grazing lands and improved commodity prices for livestock products. Dual-purpose oat cultivars are widely used in Australia for livestock grazing. Forage is grazed before stem elongation, allowing the crop to recover and produce grain for harvest. Specialist cultivars for hay are being developed to meet export quality specifications for

Australia's growing hay export trade to southeast Asia. Hay is the major oaten product in Australia, with Western Australia and South Australia being the major producers. Cereal hays are used on-farm as fodder reserves, and traded, both within the Australian animal feed industry and for export to Asian markets.

Chapter XI reviews the current and prospective importance of oats used as whole-crop forage in Europe. European livestock rearing is characterized by highly productive, high-yielding animals that need forage with high concentrations of energy and protein. New varieties of maize and barley have a higher nutritive value and can be grown in the areas occupied traditionally by oats. Ensiling, a mechanized, easy method of conservation, has replaced much of the hay in animal feeding. Maize became the most widespread silage crop due to its high yield, high energy concentration in dry matter, high content of water-soluble carbohydrates and ease of ensiling. The oat area decreased sharply while the area under silage maize increased considerably during the last thirty years and, together with pastures based on ryegrass, became the main forage and for ruminants in intensive stock raising in Europe.

The diseases of oats and their control, with an emphasis on fodder oats, is the subject of Chapter XII. A final chapter discusses and summarizes the perspectives for fodder oats by theme and region.

Other recent FAO Grassland Group publications include: *Hay and straw conservation* (Suttie, 2000a); *Grassland resource assessment* (Harris, 2001); *Silage in the tropics, with particular emphasis on smallholders* (t'Mannetje, 2000); *Managing mobility in African grasslands. The legitimization of transhumance* (in conjunction with Beijer Institute of Agricultural Economics) (Niamir-Fuller, 1999); *Transhumant grazing systems in temperate Asia* (Suttie and Reynolds, 2003); *Wild and sown grasses* (Peeters, 2004); *Site-specific grasses and herbs. Seed production and use for restoration of mountain environments* (Krautzer *et al.*, 2004); *The future is an ancient lake. Traditional knowledge, biodiversity and genetic resources for food and agriculture in Lake Chad Basin ecosystems* (Batello, Marzot and Touré, 2004); *Forage legumes for temperate grasslands* (Frame, 2004); and *Grasslands: developments – opportunities – perspectives* (Reynolds and Frame, 2004).

The FAO-AGP Grassland Index gives descriptions of and agronomic information on a wide range of forages, including oats, and a series of Country Pasture Profiles gives country-by-country descriptions of grassland-based production systems – to date, 75 countries have been described (see: http://www.fao.org/ag/AGP/AGPC/doc/GBASE/Default.htm and http://www.fao.org/ag/AGP/AGPC/doc/pasture/forage.htm).

Chapter II
Fodder oats: an overview

E.J. Stevens, K.W. Armstrong, H.J. Bezar, W.B. Griffin and J.G. Hampton

SUMMARY

Oats remain an important crop in marginal ecologies, for grain as well as for fodder, bedding, hay, silage and livestock grain feed. They are spring or autumn-sown according to climate, and tolerate acid soils. Much of the crop, both grain and forage, is consumed on-farm. Hexaploid forms, *Avena sativa* and *A. byzantina*, are the commonest source of improved cultivars, but *A. strigosa* has become important in South America. Fodder cultivars are usually a by-product of breeding for grain. There are strong genotype × cultivar reactions, and careful screening of introductions is essential. Fodder oats have immense promise in the Himalaya-Hindu Kush region, and collaboration between countries for introduction and screening of material is highly desirable. The formation of a subregional fodder oat network is recommended.

OATS IN A GLOBAL CONTEXT: GROWING AND PRODUCTION TRENDS

Oats rank around sixth in world cereal production statistics, following wheat, maize, rice, barley and sorghum. Oat grain has always been an important form of livestock feed, and provides a good source of protein, fibre and minerals, but world oat grain production declined as farm mechanization increased between 1930 and 1950. Oats remain an important grain crop for people in marginal ecologies throughout the developing world, and for specialist uses in developed economies. In many parts of the world, oats are grown for use as grain as well as for forage and fodder, straw for bedding, hay, haylage, silage and chaff. Livestock grain feed is still the primary use of oat crops, accounting for an average of around 74 percent of the world's total usage in 1991 to 1992 (Welch, 1995).

Oats are well adapted to a wide range of soil types and on acid soils can perform better than other small-grain cereals. Oats are mostly grown in cool moist climates and they can be sensitive to hot, dry weather between head emergence and maturity. For these reasons, world oat production is generally concentrated between latitudes 35–65°N, including Finland and Norway, and 20–46°S. Most of the world's production comes from spring-sown cultivars, but autumn sowing is practised in higher-altitude regions, including the Himalaya-Hindu Kush range, and in regions where summers are hot and dry. Where winters are severe, such as in Canada, Scandinavia and northern United States of America (USA), and higher-altitude regions in the tropics, short- to medium-season maturing oat cultivars are generally sown. In regions with temperate climates, oats are variously spring, winter or autumn sown, depending on regional climatic conditions, crop rotation requirements, end use and other farming practices. In

warmer regions, spring-type oats are sown in autumn to avoid summer heat and drought.

Canada, Germany, Poland, the Russian Federation, the countries of the former Soviet Union, and USA account for about 75 percent of the world's supply of grain, seed and industrial grade oats. Since the 1960s, the proportion of oats used for feed has declined in the USA and Canada; remained unchanged in the former Soviet Union countries and Poland; and increased slightly in Germany. Oats used as feed in the USA are becoming a specialty equestrian feed for racehorses, hobby farmers and breeding stock. The leading exporters of oat grain are Argentina, Australia, Canada, Finland and Sweden. The European Union, Japan, the former Soviet Union, Switzerland and USA are the principal importers of oat grain.

A significant proportion of the oat grain and forages produced on smaller, more remote farms around the world, including the Himalayan region, are consumed on-farm and never enter the commercial market place. A case study from Nepal (Stevens *et al.*, 2000), covering oats in the period dating back to the 1950s, shows how people in Afghanistan, China and Pakistan could benefit substantially from access to better cultivars to alleviate poverty and improve human and animal nutrition. These examples highlight the need for a coordinated international fodder oat network targeting resource-poor environments in relatively remote communities.

Oats are grown for grain, forage, fodder, straw, bedding, hay, haylage, silage and chaff. Food uses include oatmeal, oat flour, oat bran and oat flakes. Oats are one of the most nutritious cereals, high in protein and fibre. The protein of rolled oats is generally greater than that of other cereals. Many of the vitamins and minerals in oats are in the bran and germ, and most oat food products use the entire groat.

ADAPTATION OF *AVENA* SPECIES

The exact origin of the oat is unclear. Oat (*Avena sativa*) seeds have been found in 4 000-year-old remains in Egypt. Oats may have spread there as a weed in wheat and barley as oat cultivation began much later than that of wheat and barley. Oats descended from a number of diploid (14 chromosomes) and tetraploid wild species. These grew mainly in the countries around the Mediterranean Sea, whereas the primitive wheats were grown mainly in southwest Asia. Oats were grown for grain in western Europe and mention was made of a red oat grown for fodder around Asia Minor.

The European white or yellow-hulled oat is thought to be the progenitor of the common oat, *A. sativa*. It spread to all parts of the world where moist cool conditions prevail, and was used as a spring-sown crop for food and feed grains. The wild red oat, *A. sterilis*, is thought to have been the progenitor of the cultivated red oat, *A. byzantina*. This species spread to the regions where temperature extremes occur frequently, such as the Mediterranean, southern states of USA, Africa, South America and Australia, and was used mainly for forage production. The *A. byzantina* species generally has greater heat, drought and cold tolerance. Both species are hexaploids with 42 chromosomes (6n=42).

FODDER OAT IMPROVEMENT

The European white oat or yellow-hulled oat, *A. sativa*, and the cultivated red oat,

A. byzantina, are self pollinating hexaploids and compatible with hybridizing techniques. In recent times, plant breeders have hybridized these species to select mainly grain- and food-type cultivars that are adapted to a wider range of climatic conditions. Most plant breeding investment has been and still is directed toward the improvement of grain production for food uses, where white grain types are generally preferred. Consequently, the colour of grain of both species is becoming more like that of *A. sativa* and less like that of *A. byzantina*. According to Coffman (1977), in Argentina, where *A. byzantina* was formerly the most popular species, *A. sativa* types now predominate. In the USA, most of the spring oats are *A. sativa* whereas the winter oats in the southeast and southwest originated as *A. byzantina*. Through the development of improved cultivars, *A. byzantina* has become more like *A. sativa* in appearance.

Modern plant breeding and oat development focuses primarily on oats grown for grain, not fodder. This development and investment bias toward grain cultivars continues, with a few exceptions, resulting in very few specific global references in the literature to fodder oats. There are major monographs (Webster, 1986; Marshall and Sorrells, 1992; Welch, 1995) on grain oats, but there are few literature sources useful for fodder oat improvement, even though fodder oats are used as a multipurpose crop worldwide. They are usually autumn sown, grazed prior to stem elongation and taken to maturity for use as feed or milling grains. Traditional oats (*A. sativa*) are used as forage throughout the world.

A diploid oat (*A. strigosa*) is also grown in South America as a forage crop. Sullivan, Hales and Norton (1982) compared a diploid oat with a triticale forage for fattening cattle. Although the diploid oat had a lower nutritive value, the oat yielded more forage per unit area than did triticale.

Research reviewed by Burgess, Grant and Nickolson (1972) found that the nutritive value of oat forage is high and with dry matter digestibilities in excess of 75 percent when fed to dairy cattle. Cuddeford (1995) suggests cereal straws have similar chemical compositions but oat straw has more digestible organic matter. He suggests that straw from spring oats has a higher metabolizable energy content than winter oats, and that both are better than the other cereals in terms of available energy. Oat straw is softer and more acceptable to livestock than are other cereal straws.

Despite the extensive worldwide use of oats for forage and fodder, very little of the world's plant improvement research resources are devoted to the development of oats specifically for fodder uses; consequently, little detailed research data is available for review.

Breeding and selecting for both seedling and adult disease resistance – crown rust in particular – is an important part of oat improvement programmes in many of the world's oat grain producing areas. In Brazil, where oat crops are widely grown for forage, there are serious problem with crown rust, and a similar situation exists in Queensland, Australia, and in New Zealand, where the increasing production of oat forage has increased the incidence of crown and stem rust in oat crops. Therefore, it is not surprising that cultivars selected for grain, in environments where plant diseases are potential yield limiting factors, have often fulfilled the

requirements for improvements in forage yields. Many of the plant traits required for successful crop production apply to both forage and grain outcomes.

All cultivars in New Zealand and Australia are spring types, although some have a degree of winter cold tolerance. "Winter oats", not to be confused with "winter hardiness", is frequently used in a generic sense, such as for spring oats planted in the winter. Winter-hardy oats may have a place in the higher, cooler reaches of the Himalayan ranges, but it could be difficult to identify winter-hardy types specifically for the Temperate Asia Pasture and Fodder Working Group testing network. Breeding and selecting for improved winter hardiness is difficult. The trait is genetically complex and field selection is difficult in most environments as it is either too warm or excessively cold for effective selection.

Laboratory methods can be used, but these are expensive and imprecise. Despite these difficulties, progress, intentional or otherwise, has been made in developing oat germplasm with greater winter hardiness. Marshall (1992), in his review of winter hardiness, demonstrated that the area of winter oat adaptation in the USA showed a northward movement between the 1920s and 1960s due to the development of cultivars with improved winter hardiness.

In the Himalayan region, it is important that oats be screened for cool tolerance by sowing at high altitudes, using susceptible and known winter-hardy cultivars as controls, and using vegetative survival as the criterion for selection. In the early stages of a plant improvement programme, assessing germplasm for parental uses is crucial to success. Several countries, or their institutes, including individual plant breeders, maintain germplasm collections. Wesenberg, Briggle and Smith (1992) estimate that there are at least 22 significant *Avena* collections in the world, containing around 37 000 accessions, compared with 37 significant wheat collections, with 401 500 accessions, and 51 barley collections, with 212 000 accessions. A list of *Avena* germplasm base collections was published in *Oat Science and Technology* (1992: 799-803). The National Small Grains Collection of the United States Department of Agriculture Agriculture Research Service (USDA-ARS NSGC) is a collection comprising more than 113 000 accessions of wheat, barley, oats, rice, rye and triticale, and a comprehensive collection of wild and other cultivated species. It is maintained at several sites.

The NSGC germplasm is relatively easily available, through the internet or by mail. However, this material, unless its field performance is already known, is best screened within established programmes. Obtaining and evaluating germplasm can be a costly business, and is best done, in the first instance, within established programmes. Cultivar development involves the selection of parents, hybridization among parents, inbreeding, and selection among the resulting progeny, followed by replicated testing for yield and other important quantitative traits, with a final stage of multiplication, maintenance and distribution of seed.

The cultivar improvement objectives will reflect producers' needs in the target environmental region, and the end uses of the crop, as grain, straw or fodder. Successful plant improvement programmes are difficult and expensive to replicate in the short term. Therefore,

successful networking among the Himalayan communities, site controllers and researchers is the obvious recipe for the Temperate Asia Pasture and Fodder Network to accomplish its mission successfully.

GENOTYPE BY ENVIRONMENT INTERACTIONS

Traditionally, discarded oat cultivars developed for grain production have been, and still are being, used as forage and fodder worldwide. Screening for forage and fodder production has used grain types that may not have met the target grain yields, but nevertheless have potential forage capability, so consequently they are streamed for potential forage uses by researchers whose primary focus is on improving grain yield. For example, dual-purpose cultivars selected for New Zealand from Canadian and European stocks were used up until the late 1980s, when the first cultivar (Charisma) selected purely for forage was released by Crop and Food Research (CFR). Until then, Mapua 70, a reselection from Makuru, developed from UK cultivar Milford, was the major forage and milling oat in New Zealand. A discarded grain cultivar (Lordship) from the New Zealand oat programme was released in Australia as a forage oat, although it is currently used for hay. An unreleased CFR cultivar with good grain yield is a potential candidate for release as a forage oat in New Zealand. It has also performed well in forage trials in the USA west of the Rocky Mountains and is included in lines from New Zealand to be tested in the Himalayas.

According to Stevens *et al.* (2000), oat cultivars from Canada, Europe and New Zealand, introduced into Asia over the past 20 years, continue to play a highly significant and strategically important role in feeding livestock across a wide range of ecologies, especially within the poorer regions of countries bordering the Himalayas, where they are used as green feed or oaten hay.

Considerable genotype by environment interaction has been noted across latitude, altitude and seasonal sequences, with some cultivars producing significantly better than others in some regions and under certain management regimes. Cultivars bred more recently, and previously-discarded populations, have never been tested systematically in these areas. However, if such populations or cultivars can be properly introduced and systematically evaluated and tested, there will remain the need for reliable maintainance and seed production and distribution.

POTENTIAL FOR OATS IN THE HIMALAYA-HINDU KUSH REGION

Fodder oats have since the 1950s and 1960s grown to become a major forage and fodder crop along the Himalaya-Hindu Kush (HHK) zone, from Afghanistan to Myanmar. Increasingly, cereal fodders are being used to encourage and facilitate zero and tethered grazing. The HHK range is characterized by steep topography and climatic extremes, including very cold and prolonged winters at higher altitudes, variable soil types, and lack of irrigation in dry regions limiting the choice of agricultural activities. Crop production is limited to below circa 3 000 m above sea level.

Animal rearing is an important occupation in this region, at all altitudes. Above 3 000 m, overgrazing is a major problem and in some areas it has resulted in the destruction of the natural vegeta-

tion and forest cover. Alternative fodder sources are needed, particularly those that encourage and can sustain a shift from free grazing to zero grazing-tethered grazing, and to cut-and-carry systems. The fodder sources should be linked with a shift from lower value animals, such as cattle, sheep and goats, to buffalo. Buffalo can provide milk, meat and useful draught power. Remedial action is underway in a few areas, for example in Pakistan (Aga Khan Rural Support Programme) and Nepal, where it has become clear that widespread nationally coordinated attempts to resolve the ecological consequences of overgrazing will require a considerable improvement in the productive capability of land currently used for arable purposes. This will sustain the current animal population and provide measurable material benefits to the communities living in these higher altitude zones.

To achieve this, the range of oat cultivars available may need to be updated with winter-hardy types for use in the higher altitude zones. New cultivars are needed to extend the existing range of options at the higher altitude levels along the HKK. Cultivars with an improved yield capability that can be also grown at higher elevations than the current climatic limits for arable agriculture could relieve some of the overgrazing pressures and destruction of forest.

Fodder oats are used throughout the HHK region for grazing, feeding and bedding milking animals, young stock and draught animals. Some farmers use a cut-and-carry system, which is very effective in utilizing forage, by reducing waste normally associated with direct grazing. By using cut-and-carry systems, farmers have greater control over harvest timing and cutting height, and consequently over the vegetative recovery capability of the oat crop. The system also enables farmers to use overlapping cropping methods to provide a continuous supply of green feed for livestock.

Oats in general are more suited to cut-and-carry systems than to grazing, particularly in cold environments. Cereals, unlike pasture grasses, and oats in particular, have not been extensively bred for direct grazing, but, despite this, direct grazing of cereals, including oats, can work well in warmer regions.

As the available land currently used for food production becomes scarce in relation to increasing population, and the need for greater food production increases, more research is needed to develop special purpose forage cultivars that fit specific end uses. There are few oat breeding programmes where the primary objective is developing oats for forage, and very little work is underway to develop germplasm for conditions like the cool and high altitude regions found in the parts of the Himalayas.

A point at issue is to consider the potential for quantum leaps in oat cultivar performance were the oat crop a mandated food crop of an International Agriculture Research Centre, such as ICARDA or CIMMYT. It would provide potential spin-offs by providing the basis for smaller oat breeding operators to develop germplasm specifically for grain, forage and fodder uses, including lowering the temperature threshold at which oat germplasm can grow, and to produce higher yields of forage and fodder for livestock uses in cool regions, including the HHK region. Despite international funding issues, local crop improvement

programmes have historically made the best possible use of whatever materials are locally available. These sources have been augmented by genetic material introduced from outside the region, bred in the overlapping ecologies of Europe, North America, Canada, Australia and New Zealand, and circulated via the Quaker International Oat Nursery (QION), FAO and a number of bilateral aid programmes.

Sadly, so far, there has been no coordinated international crop improvement programme for oats and fodder oats akin to the programmes for wheat, maize, rice and sorghum, for example. This leaves networks such as the Temperate Asia Pasture and Fodder Working Group having to look after their own needs. With the advent of plant variety protection, combined with a down turn in international aid, it has become increasingly difficult for smaller, less well endowed, developing countries along the HKK to obtain direct and to exchange germplasm, and otherwise to obtain access to, evaluate, develop, maintain and produce seed of improved, purpose-bred, fodder oats for stress-prone environments.

This has occurred at a time when, more than ever, improved cultivars of fodder oats are needed to help alleviate poverty, and to restore and manage the environment in sustainable ways that enhance local seed and food security. New, alternative networking approaches are needed, embodying the concepts introduced and discussed here.

The Himalayan region's growers need access to modern cultivars without the imposition of the business and compliance-administration costs associated with plant variety protection and seed distribution schemes in the countries where these cultivars are developed. To find new germplasm and cultivars, the network should identify plant improvement groups willing to supply material and that are prepared to forgo seed royalties. This would mean substantial savings for the organizers, in a community-based evaluation system where plant variety protection and royalty collection are not village-based issues. The outcome would provide a rapid route to market for new cultivars. This would enable growers to take immediate advantage of new cultivars and technologies, free from all business compliance and cultivar ownership issues in the initial stages.

However, the mechanisms for the funding of crop improvement projects, inside existing programmes, will need to be investigated by international assistance agencies and national governments. Businesses sponsorships could be tried. Despite the problems associated with distributing modern oat cultivars, and plant variety protection and ownership issues, a wide range of oat germplasm for developing new populations is available to any network of plant breeders who respect the conventions of germplasm exchange and access. Released cultivars are usually maintained by the originating owner or their agent, and could be available for germplasm enhancement projects if not for commercial use.

CONCLUSIONS AND PROSPECTS

The potential for an Oat Fodder Network as presented by Stevens *et al.* (2000) is generally accepted by oat research workers as the basis for moving forward to exploit the potential of the crop for the Himalayan region. Realistically, a structure such as an

Oat Fodder Network is required to actively obtain and pre-screen material, prior to committing unknown material directly into a testing network. The Oat Fodder Network should also aim to develop a low cost preliminary screening system for a larger number of oat lines in the HHK region, from which selections can be made for entry into the more formalized testing system.

Hull-less (naked) oat is a variant of *A. sativa*, the cultivated hexaploid – a traditional grain and fodder oat, but without a hull. Naked oat cultivars offer farming families in this region a dual-purpose cropping option: fodder and an alternative human food source. Naked oats are hull-less grains, where the caryopsis (groat) separates from surrounding plant tissue during the threshing process. Hull-less grains could be milled into flour by local householders. However, oat grains (hulled and hull-less) also have a higher oil content compared with other cereal grains, such as wheat, and consequently the shelf life for oat flour may be shorter than for wheat flour. Rancidity in damaged oat grains or milled flour can occur, affecting taste, but is not considered of any consequence for animal feeding. Several countries are developing naked oats for use as a food crop.

Diploid (*A. strigosa*) oat cultivars are another fodder crop option for use in the Himalayan region. More suited to forage production than grain production, a diploid cultivar in New Zealand field trials produced high yields of vegetative fodder in winter forage trials, from autumn sowing. Diploids are widely grown in South America for forage uses. The grain contains a husk, but naked varieties are available. No references for potential use as a food for milling into flour had been found at the time of writing. In a recent glasshouse experiment at CFR, the diploid cultivar was observed to produced a much larger root mass than traditional oat cultivars. This was not a controlled experiment for measuring root mass, but the differences between the diploid and a traditional hexaploid oat root mass on this occasion were large.

If diploid cultivars produce greater root mass under field conditions, diploids may have additional benefits in erosion control, in addition to fodder or hay uses. However, the authors emphasize that no research references had been identified to verify this observation.

Chapter III
Fodder oats in North America

Joanna Fraser and Duane McCartney

SUMMARY

Oats (*Avena sativa* L.) are grown on over 1.8 million hectares in Canada and 800 000 ha in the United States of America, for human consumption as well as fodder. Oats are sometimes grazed, but the main use is for hay and silage, fulfilling an important role as feed for livestock operations in the Northern Great Plains of North America. Oats can be intercropped for silage and autumn grazing, and used as fodder for swath grazing. In winter oat growing areas, oats are integrated into pasture-silage systems. Cultivar selection is important: oat breeders, agronomists and livestock nutritionists need to work together closely to evaluate selection criteria for forage oats. With proper cultivar selection and management, there should be increased interest in oats for fodder where the economics warrant it.

INTRODUCTION

In Canada, oat (*Avena sativa* L.) is grown as livestock feed in the form of grain, silage, hay and pasture; the food industry in North America uses approximately 110 million bushels (1.7 million tonnes) of oats, about 90 percent being grown in Canada (Quaker Oats Company, pers. comm., 2004). The racehorse industry uses about 80–85 million bushels (1.3 million tonnes) of oat for feed and 90 percent originates from Canada. Oats for grain and forage or fodder are grown on over 1.8 million hectares in Canada (Statistics Canada, 2001) and 800 000 ha in the United States of America (USA) (USDA, 2003). In Canada, oats are among the top five crops in terms of area grown in British Columbia, Manitoba and New Brunswick (Statistics Canada, 2001). Manitoba and Saskatchewan in central Canada have the largest area sown to oats, with 40 percent being grown for human consumption (Dr B. Rossnagel, University of Saskatchewan, pers. comm., 2004). Over 40 percent of farm cash receipts came from oats in Manitoba, followed by Saskatchewan at 33.9 percent (Manitoba Agriculture, Food and Rural Initiatives, 2003). In Manitoba, the area sown to oats increased by about 10 percent between 1999 (810 000 ha) and 2002 (1.1 million hectares). Alberta has the most oats grown for feeding livestock (Hartman, 2001). In the USA, North and South Dakota, Minnesota, Iowa and Wisconsin have the greatest areas harvested for oats. North Dakota markets most of its oats outside the state, while in Wisconsin, growers retain most for on-farm feed. Oat areas are declining in the USA, with a corresponding increase in Canada. This trend was expected to continue (Lawrie, 1999) because of the reduced use of the grain for feed, and failure of yields to keep pace with increases in maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) yields (Marshall, McDaniel and Cregger, 1992). USA imports over 70 percent of its oats from Canada (Lawrie, 1999), as feed for racehorses and for milling, cereal and pet food (Manitoba Agriculture, Food and Rural Initiatives, 2003).

In the USA, oat is the most popular cool season forage in the Northern Great Plains, i.e. North Dakota, South Dakota, Minnesota and Montana (Poland, Carr and Tisor, 2002). Oats, especially for feed, are normally used close to where produced, due to their bulk density, caused by the large hull, which is approximately 250 to 330 g kg^{-1} of kernel weight. Oat grain has an average protein content of 11.5 percent compared with 12.5–13 percent for barley (*Hordeum vulgare* L.) (Cowbytes, 2004). Oat hulls, a by-product of milling, is a feed commodity that contains hulls and fragments of the endosperm and constitutes up to 25 percent of the total weight of the grain (Thompson *et al.*, 2000). In Canada, the oat hull has a high fibre content, with neutral detergent fibre (NDF) averaging 853 g kg^{-1} and acid detergent fibre (ADF) averaging 464 g kg^{-1} dry matter (DM) (Thompson *et al.*, 2000). There is a large market for oat hulls as a source of fibre for feeding cattle, sheep and horses (Beauchemin, Farr and Rode, 1991; Schrickel, Burrows and Ingemansen, 1992). However, their nutritive value is similar to that of a low quality forage. Treating this by-product with anhydrous ammonia at 3 percent dry weight basis increased voluntary intake by growing steers and improved potential degradable NDF and ADF by 41 and 35 percent, respectively (Thompson *et al.*, 2002).

Oat straw is grazed or fed (Figure 3.1), but feed quality is lower than at earlier

Figure 3.1
Feeding oat straw to cattle in winter

stages of maturity (Youngs and Forsberg, 1987); it is often used as winter bedding and feed for beef cattle (Schrickel, Burrows and Ingemansen, 1992).

In western Canada, oat and barley straw have average protein contents of 480 and 540 g kg^{-1}, respectively, and have a higher feeding value than triticale (×Triticosecale Wittmack) or wheat (*Triticum aestivum* L.) straw (Coxworth *et al.*, 1981; Wedin and Klopfenstein, 1985; Cowbytes, 2004). White, Hartman and Bergman (1981) in Montana compared the *in vitro* digestibility of wheat, barley and oat straw. Oat straw had the best digestibility, averaging 45 percent. It had slightly less crude protein (CP) than barley, but more than wheat. The addition of ammonia has a positive effect on the digestibility of oat straw used for feed. Horton (1978) and Horton and Steacy (1979) treated barley, oat and wheat straw with anhydrous ammonia, giving increased straw intake, CP and digestibility when fed to cattle. Other uses for oats, such as conservation (i.e. cover crops in no-till systems), or sowing as a companion crop, have been gaining relative to use for grain (Schrickel, Burrows and Ingemansen, 1992), but in livestock operations the greatest use of oats is for fodder or grain. The following sections review the role of oats for fodder (i.e. pasture, hay or silage) in North America.

FODDER OATS – PAST AND PRESENT USE IN NORTH AMERICA

Oats as a pure stand – Canada

Cereals such as oats are the first choice for annual pasture or silage in many regions of western Canada because seed is readily available and the crop is easy to establish (Aasen and Baron, 1993). Compared with other cereals, oats are more tolerant of acid soils and excessive soil moisture, but less tolerant of salinity than barley or wheat (Kirkland, 2004).

In a review of early pasture research in Ontario, central Canada, Clark and Poincelot (1996) reported that one approach to dealing with the seasonality of pasture yield involved the use of mixtures of annual and biennial forages, such as oats, sorghum (*Sorghum bicolor* L.), sweet-clover (*Melilotus alba* L.) and red clover (*Trifolium pratense* L.) for annual pastures, with annual yields averaging 3 000 kg DM ha^{-1} (Zavitz and Squirrell, 1919). At the Agriculture and Agri-Food Canada Research Centre, Brandon, Manitoba, in central Canada (Department of Agriculture, 1924), annual forage crops trials included oats, which yielded the highest, at 9 245 kg ha^{-1}. At the Agriculture and Agri-Food Canada Research Centre in Lacombe, Alberta, western Canada, in the 1930s, oats were superior to barley and wheat as annual pasture (Experimental Station, Lacombe, 1936). By the 1940s, annual pastures were of considerable importance to the livestock industry in Alberta as they could be used as supplementary pastures for cattle, horses or sheep, and constituted the principal cultivated pasture for swine and poultry. Oat was the most satisfactory forage for annual pastures, especially late-maturing cultivars. However, oats alone did not yield as much forage as with autumn rye or rape (Dominion Department of Agriculture, 1940). Burgess, Grant and Nickolson (1972) in New Brunswick, eastern Canada, showed that forage oats should be harvested at the milk stage of growth to obtain the maximum yield of digestible DM while maintaining acceptable voluntary intake

levels in sheep. Later studies in northern Saskatchewan (Robertson, 1980) used sheep to compare oats and barley pastures with brome-lucerne (*Bromus inermis* L. + *Medicago sativa* L.) pastures. The grazing season for the brome+lucerne began during the first week in June, and the annual cereals pastures were first grazed after mid-June. On average, oats provided 88 grazing days; barley, 82 grazing days; and brome+lucerne, 114 grazing days. Average liveweight gains per hectare during the experiment were similar for oats and for brome+lucerne (328 and 330 kg), followed by barley (305 kg ha^{-1}). Annual DM yields averaged 5.9 t ha^{-1} for the annuals and 5.4 t ha^{-1} for brome+lucerne. Perennials were utilized more efficiently than annuals due to the greater degree of trampling and wastage on annual pastures. Robertson (1980) concluded that oats could produce gains equal to those obtained on perennial grass+legume mixtures and would be available for grazing within 6–7 weeks of sowing. The quality of the oat pasture could in part be controlled by subdividing the area to be grazed with cross-fences and spacing the dates of sowing by 2–3 week intervals. Oats could also provide pasture during the establishment year of perennial forages. Oat pastures could be used as a source of pasture and "emergency" feed by cattle farmers, but the input costs of growing annuals for pasture were considerably higher than perennials, although their potential is greatest when utilized to overcome shortages of perennial pasture in years of below-average precipitation.

In Alberta, research in 1979 indicated that the old recommendation for growing oats for summer grazing was being questioned. While oats were was found to have a place on Grey Wooded soils, DM yields on Black and on irrigated Brown soils were much lower than spring-sown winter cereals such as winter wheat, autumn rye or winter triticale (Riemer, 1988). In contrast, evaluations of oat under simulated grazing (two to five cuts) in central Alberta from 1979 to 1983 (Berkenkamp and Meeres, 1988) showed oats to be consistently the best pasture, with cv. Foothill averaging 3 347 and 2 106 kg ha^{-1} on two different soil types. Spring cereals, including oats, showed more rapid growth in the spring and were ready for grazing earlier, whereas Italian ryegrass (*Lolium multiflorum* L.) and spring-sown winter-type cereals such as rye grew more in midsummer, and into the autumn if moisture was adequate (Berkenkamp and Meeres, 1988).

Beacom (1991), in northeastern Saskatchewan, summarized several studies and reported that supplementary oat pastures yielded 3 800 to 6 000 kg ha^{-1}, provided 100 to 150 steer days of grazing per hectare, and extended the grazing season by as much as 40 days. Kibite *et al.* (2002) evaluated oat and barley cultivars sown in mid-May and in late June on two soil types in central Alberta. Cultivars were harvested at their respective heading dates, and then two and three weeks later. Average DM yield of early sown cereals were about 5 000 kg ha^{-1}, or 35 percent more than late-sown ones. For both early and late-sown groups, yields maximized at either two or three weeks after heading, but not consistently at either harvest date. Oat cultivars generally out-yielded the standard barley cultivar for forage by 2.6 and 3.2 t ha^{-1} for early and late sown crops, respectively. Early sown oats yielded 14.7 t ha^{-1}, but the late sown oats yielded only 9.9 t ha^{-1}. Barley generally

had higher digestibility and protein than oats, but, unexpectedly, NDF was not always lower for barley than for oats. Sowing date had no consistent effect on nutritive value at time of harvest, so late sowing was not advantageous in this regard. Late sowing reduced yield and did not improve nutritive value.

Several studies in western Canada (Aasen and Baron, 1993; Baron *et al.*, 1993a; Johnson, Kowalenko and Tremblay, 1998; McCartney *et al.*, 2004a) have also shown that spring- or autumn-sown cereals such as oat, barley, wheat, rye or triticale provide excellent summer or autumn pasture or silage. Oats are one of the three major cereals used for silage in western Canada. In central and northern Alberta, oat yields more silage or green feed per unit area than any other cereal crop (Hartman, 2000), especially when fertilized with nitrogen (Mahli *et al.*, 1987). In northern Alberta, oats have the highest total DM and total energy of all cereals in the Grey Wooded soil areas. They yield more total DM, but not necessarily more digestible material per unit area than other cereals on Black soils in northern and central parts of the province. In southern Alberta, oat are recommended for silage production, but yield 5 to 30 percent less DM than other cereals, such as barley (Kirkland, 2004).

Christensen (1993) summarized 18 years of data on nutritive values of different forages in Saskatchewan and concluded that oat forage, for maximum nutritive value, should be harvested at the early dough stage, as it could lose feeding value with advancing maturity. In northeastern Saskatchewan, oat silage yielded 7 346 kg ha^{-1} DM, which was similar to barley and triticale. Barley and oat silage did not differ in chemical composition, and feed intake by heifers was similar. Average daily gain was greatest with barley (0.65 kg day^{-1}) followed by oat (0.57 kg day^{-1}). These results appeared to be primarily related to a lower digestibility of the oat silage. Where oats outyield barley, oats may be a more economical crop if supplemented with grain (McCartney and Vaage, 1994). In a plot trial to evaluate barley and oats for silage in northeastern Saskatchewan, oat silage yielded 8 330 kg ha^{-1} while the barley silage yielded 7 410 kg ha^{-1}. However, the CP of the barley was 118 g kg^{-1} compared with only 103 g kg^{-1} for oats.

Abeysekara (2003) in Saskatoon evaluated three oat cultivars for feeding dairy cows: AC Assiniboia for silage; CDC Bell for hay; and CDC Baler for hay. The AC Assiniboia silage was comparable to AC Rosser, a six-row feed barley, in chemical and digestive characteristics and in production aspects. CDC Bell and CDC Baler hay were not comparable to the silages in chemical or digestive characteristics, but were comparable to each other in degradability characteristics. The author concluded that AC Assiniboia silage could be substituted for AC Rosser barley silage in dairy cow rations.

To date, there has been little research on oat varieties for hay in Canada. There is a definite demand for Manitoba oat hay for export, especially to Japan. Preliminary trials are in progress to evaluate cultivars that might be suitable for hay export (Kostiuk, unpublished). In years of drought, growing oats for hay could be a real advantage as an alternative to timothy (*Phleum pratense* L.) hay, as timothy requires more moisture for establishment.

Oats as a pure stand – United States of America

In Wisconsin, trials on yields and forage quality of three oat cultivars over a range of sowing dates showed that the earlier oat is sown, the higher the milk stage yield per unit area and per tonne of forage (Oplinger and Maloney, 1997). Summer grazing trials in North Dakota in the Northern Great Plains region have shown that, in some years, oats have higher forage DM yields and more animal grazing days than barley, but in other years, cattle performance on barley or oats does not differ (Poland, Carr and Tisor, 2002). Trials in North Dakota showed that oat cultivars developed for forage, such as Celsia, Mammoth and Triple Crown, tended to produce more DM yield than cultivars developed for grain, such as Paul and Whitestone (Carr, Poland and Trisor, 2000). In earlier trials, oats cv. Dumont and cv. Magnum were superior to barley for yield when sown pure and when mixed with pea (*Pisum sativum*) (Carr *et al.*, 1998), but in another study, DM yield of oats cv. Dumont did not differ from barley. This suggests that oat cultivar selection affects forage yield (Poland and Carr, 2002).

Oat mixtures in North America

In North America, the use of oats in crop mixtures is common in marginal cropping areas. This is done to ensure some yield in case a pure stand fails. In Alaska, oats and pea are considered complementary, with pea compensating for the decline in oat quality when harvested at the early boot to milk stage (Brundage and Klebesadel, 1970; Brundage, Taylor and Burton, 1979). Pea+oat+vetch (*Vicia* spp.) mixtures are grown in Newfoundland. This mixture has traditionally been grown to provide a high quality ruminant feed in late summer and early autumn (McKenzie and Spaner, 1999). This mixture is normally cut as needed, and fed fresh daily. In Alberta, Berkenkamp and Meeres (1987) reported that on low fertility soils oat+sunflower (*Helianthus annuus* L.) mixtures yielded more DM than pure sunflower, but did not differ on fertile soils. In northeastern Saskatchewan, oat and spring-sown winter wheat were sown together. The regrowth of the winter wheat following removal of an oat crop for silage supported cows over a 60-day period from 5 August to 5 October, with a daily rate of gain of 0.5 kg (Beacom, 1991). In another study, at Melfort, winter wheat or autumn rye was sown with oats for silage and autumn grazing. The oat crop was removed as silage in June at 4.0 and 3.4 t ha^{-1} on the autumn rye and winter wheat fields, respectively. The under sown annuals plus oat regrowth provided 112 cow day ha^{-1} of grazing and supported a daily gain of 1.07 kg (Beacom, 1991).

Intercropping spring and winter cereals provides earlier grazing than winter cereals alone, due to the early growth of the spring cereal. Intercrops continue to accumulate DM later in the season compared with spring cereals alone (Baron *et al.*, 1993a, b). The advantage of this system is that the forage distribution can be increased during the traditional grazing period and extended into the autumn (Baron *et al.*, 1999; Poland *et al.*, 2003; McCartney *et al.*, 2004a). A silage-pasture intercrop system, utilizing a spring cereal (barley, oats or triticale) for silage and winter cereals (autumn rye, winter triticale or winter wheat) as regrowth pasture after the silage has been removed, is a

system that provides a high quality silage crop along with autumn pasture (Aasen, 1992; Baron, Dick and de St Remy, 1994; McCartney, 2004a). However, adequate autumn regrowth depends on the time of the first harvest of the spring cereal component when mixed with winter cereals (Baron *et al.*, 1995). In another study in Alberta, Baron, Dick and de St Remy (1994) showed that late sowing of oats either pure or in mixtures reduced total annual DM yield (2 cuts) by 42 percent, but that late sowing did not limit regrowth of winter cereals in mixtures given equal regrowth periods. With adequate moisture, the cereal intercrop system is a feasible alternative where annual forage is required for full season summer pasture. In a study of cropping systems for silage and pasture in northeastern Saskatchewan, McCartney *et al.* (2004a) evaluated herbage yield of spring and autumn cereal intercrops clipped for silage when barley (early cut) and oats (late cut) reached soft dough stage, and again late in the autumn. Silage yield of oat monocrop was 8 830 kg ha^{-1}, exceeding oat intercropped (8 040 kg ha^{-1}), barley pure crop (7 410 kg ha^{-1}), barley intercrop (6 870 kg ha^{-1}), late cut autumn cereal pure crop (4 700 g ha^{-1}) and early cut autumn pure crop (3 670 kg ha^{-1}). CP content was 14 percent to 35 percent higher in the intercrop system than in the corresponding spring cereal crop system. CP contents of oat intercrop and barley intercrop were similar. NDF of treatments containing barley were 15 percent lower than those containing oats. The ADF content of the barley treatment was 22 percent lower than the corresponding cropping system with oats. The ranking and relative productivity of the regrowth for autumn pastures was: deferred grazing treatment harvested only in the autumn (5 560 kg ha^{-1}) > early cut autumn cereal (3 700 kg ha^{-1}) > late-cut autumn cereal (2 730 kg ha^{-1}) > barley intercrop (1 690 kg ha^{-1}) > oat intercrop (1 330 kg ha^{-1}) > barley (800 kg ha^{-1}). The autumn pasture yield in cropping systems without spring cereals was 2.4 times that with spring cereals.

Seed rate and ratios of spring and autumn crop components can have an effect on annual forage production. McCartney *et al.* (2004c) found that the *proportion* of spring-sown oat sown with spring-sown autumn rye or Italian ryegrass rather than *total stand* seed rate, was the major factor affecting the silage and autumn regrowth yields. High seed rates may improve crop competitive ability and reduce the chance of problematic future weed infestations. The more rapid growth of the spring crop, such as oat, relative to the autumn crop helped to suppress weeds. The authors concluded that a forage sward with greater than 60 percent oats along with a higher than normal total spring and autumn crop component at a seed rate of 400 seeds m^{-2} represented a possible integrated weed management strategy, but the later silage cut time for oat compared with barley sometimes allowed for the development of weed infestation capable of reducing yields in the oat mixture.

In northern Ontario, growing oats with barley is a strategy whereby producers can optimize the output from fields that are variable from year to year. Growing mixtures can also serve as "insurance" against diseases that affect components separately (Rowsell *et al.*, 1999). Oats mixed with pea for forage tend to yield equally to

pure oats in the south of the province, but may be lower in the northern part (Johnston, Wheeler and McKinlay, 1999). Johnston and Garner (2000a) showed that, in northern Ontario, oats+winter triticale silage mixtures had significantly higher ADF (39.0 g kg^{-1} DM) than oats+autumn rye mixtures (35.1 g kg^{-1} DM). In the same study, where pasture yields and quality were measured, yield was highest in oats+annual ryegrass; overall yields ranged from 2.9 to 4.0 t ha^{-1} across sites (Johnston and Garner, 2000b).

In southwestern North Dakota, sowing either spring barley, oat or triticale with winter rye, triticale or wheat produced about 3 360 kg ha^{-1} DM by mid-July, with regrowth of the winter cereal contributing an additional 504 kg ha^{-1} in the autumn (Poland *et al.*, 2003). Winter rye regrowth was sufficient to provide limited amounts of forage for grazing the following spring. In western North Dakota, Manske and Nelson (1995) reported that oat+pea intercrops, millet (*Panicum* spp.) and autumn rye worked well in annual grazing systems. In a study on water use and relative feed value in Montana, Pikul, Aase and Cochran (2004) showed that oat+pea hay was a suitable crop for the semi-arid growing conditions of the Northern Great Plains and met the needs of producers for high quality hay. When oat is used as forage in these regions, it is sown at 25–50 percent higher seed rates than normal for grain purposes, with similar fertility inputs (Cash and Wiehman, 1997). Elsewhere, Oplinger and Maloney (1997) in Wisconsin reported that autumn forage DM yields of spring cereals were three to five times those of autumn cereals. They also indicated that oat, barley and triticale sown with a winter cereal in the autumn averaged 143 g kg^{-1} CP, compared with 190 g kg^{-1} in winter cereals sown alone. However, ADF (223 g kg^{-1}) and NDF (407 g kg^{-1}) were higher in winter than in spring cereals (wheat, rye, triticale or oats) sown alone in the autumn. ADF and NDF values were also much higher in the spring forage compared with autumn forage (Oplinger and Maloney, 1997). In Iowa, oat intercropped with berseem (*Trifolium alexandrinum* L.) had economic and biological advantages for use as a rotation crop. Holland and Brummer (1999) found that adding oat to berseem reduced DM of forage and weeds, clover stands and relative maturity of clover, but increased total crop DM. Oat and maize were included in pasture mixture studies for early weaned lambs in Minnesota (Wedin and Jordan, 1961). The authors reported that total liveweight gain per unit area was greatest for an oat+rape (*Brassica napus* var. *biennis*) mixture than for either oat+pea followed by Sudan grass (*Sorghum bicolor* (L.) Moench) or pea followed by sod-sown maize (350, 320 and 326 kg ha^{-1}, respectively). In North Dakota, DM yields of winter and spring cereals, including oat, were lower in mixtures compared with the spring cereals when sown alone, with yield reductions of up to 20 percent in July (Poland *et al.*, 2003).

Winter oats

The term "winter oats" is frequently used in a generic sense to indicate oats sown in the autumn and winter, and is not to be confused with "winter hardiness" in oats (Stevens *et al.*, 2002). Winter oat is commonly used for pasture and forage in southern parts of the USA. Oat is valuable as a winter pasture as it provides excellent

forage at a time when other high-protein feeds are scarce (Schrickel *et al.*, 1992). Hoffman and Livezey (1987) reported that Texas ranked fourth in the USA in total area sown to oats, but produced only 4 percent of oats grown for grain. These oat pastures have complemented the expansion of the cattle industry in Texas. California produces more small-grain hay than any other state and most of this hay is cultivated or wild oat (Schrickel *et al.*, 1992). In California, where urban areas are often close to agricultural areas, lucerne+oat hay is often sold to horse owners, who prefer this forage mixture (Lanini *et al.*, 1999). In this area, cv. Montezuma is preferred due to seed availability and favourable forage characteristics, and has provided equal or greater yields than other cultivars (Lanini and Bendixen, 1990). However, in Arkansas, oats generally produce less winter forage for grazing than do wheat, rye or annual ryegrass (Sandage, 2002).

When used for pasture or other forage, winter oats are sown at a seed rate 50 to 100 percent higher than when the crop is grown for grain (Shands and Chapman, 1961). Recommended seed rates have ranged from 100 to 150 kg ha^{-1} (Denman and Arnold, 1970). In Tennessee, the upper end of this range has yielded the most autumn forage under heavy grazing (Parks and Chapman, 1960). Early autumn sowing of winter oats increases the amount of forage that can be used before the weather becomes too cool for significant growth. Sowing dates depend on the location of the winter oats area, and whether the crop is intended for grain or forage (Marshall, McDaniel and Cregger, 1992).

In the coastal areas of southeastern USA, winter oats are commonly grazed in the autumn and early spring for part of the growing period, before allowing the crop to produce grain (Delorit, Greub and Algren, 1984; Schrickel, Burrows and Ingemansen, 1992). In the Coastal Plains, oats are clipped or grazed in early February, and further north, in the Piedmont areas of the southeastern USA, they are cut or grazed two weeks later (Schrickel, Burrows and Ingemansen, 1992). Burton *et al.* (1952) recommended that oat be rotationally grazed to a minimum of 75 to 102 mm. In a grazing study with steers in Texas over a 7-year period, Norris and Kruse (1967) found that a "medium" animal stocking rate of 1 ha^{-1} during the winter and 0.7 ha^{-1} during spring resulted in the highest gains per unit area. The same authors reported that steers grazing oats for an average of 97 days per season had average liveweight gains of 900 g d^{-1} $head^{-1}$ for that period and 214 kg ha^{-1} for the season. The average daily gain of steers grazing oats oversown on coastal Bermuda grass (*Cynodon dactylon* (L.)) sod in Georgia was 1 kg $head^{-1}$ (Utley, Marchant and McCormick, 1976). In Texas, under average conditions, Atkins, McDaniel and Gardenhire (1969) indicated that winter oat pastures may produce between 3.4 and 6.7 t ha^{-1} DM forage, and that with adequate fertilization and irrigation, yields might be as high as 11.2 t ha^{-1}. In addition to grazing, the crop may be subsequently used for haylage, hay or silage (Marshall, McDaniel and Cregger, 1992). From one-quarter to three-quarters of the land area for winter oat in the Gulf Coast and Coastal Plain areas may not be used for grain, depending on the year. However, careful grazing management is needed if the crop is to produce a good crop of stored feed or grain. In Baton Rouge, Louisiana, winter

oats were clipped in small plots from early December to either 15 February, 1 or 15 March during a 5-year period. Clipping until 1 or 15 March increased forage yields by an average of 672 and 1 400 kg DM ha^{-1} (Viator *et al.*, 1982). Grain yields were not reduced when cutting was stopped on 15 February, but extending cutting to 15 March reduced grain yields by 44 percent.

Winter oat can produce good yields of silage or hay in northern areas, but is normally not grazed. In Maryland, forage DM yields at the soft dough stage ranged from 5.5 to 6.9 t ha^{-1}. In mild winters, where the crop did not winterkill, yields ranged up to 10 t ha^{-1} (Coffman 1962). Oat cv. Norline was popular in northern areas of the winter oat region for a number of years for grain or forage (Marshall, McDaniel and Cregger, 1992). In southeastern Pennsylvania, Norline was sown in late September and cut at boot, milk and dough growth stages for assessing DM yield and quality. The highest CP yield – 745 kg ha^{-1} – was at the boot stage, and the highest total digestible nutrients (TDN) yield – 5.5 t ha^{-1} – was at the milk stage (Marshall and Yocum, 1971). The authors concluded that the value of the forage appeared to be substantially greater than the expected return from grain. In view of the value of winter oat for forage in the northern parts of the winter oat region of New York and Maryland, a winter-hardy cultivar, Walken, was developed for either forage or grain (Finkner *et al.*, 1971).

Figure 3.2
Oats baled green to be used as green feed

Oats as a companion crop for perennials

Oat has been used as a companion crop for sowing forages since the early 1900s in western Canada. In central Saskatchewan, oat was used at rates from 18 kg ha^{-1} to 72 kg ha^{-1} with 17 kg ha^{-1} of sweet clover (*Melilotus officinalis, M. alba*) (Tinline, 1924). In the 1920s, weed control options were very limited and the oat companion crop at 27 to 54 kg ha^{-1} helped suppress weeds and allowed the highest sweet clover hay yields. At the Agriculture and Agri-Food Research Centre, in southern Saskatchewan, Jefferson and Zentner (1994) sowed oats as a companion crop with lucerne on irrigated land. Lucerne sown alone produced much less than oat sown with lucerne or oats sown alone in the establishment year. Over the 3-year period, undersowing and harvesting the oats for hay (Figure 3.2) produced slightly more forage than lucerne sown alone. Oats as a companion crop provides some protection against soil erosion and helps in weed control, but the main problems with this system is that the oats compete with the perennial forage and weeds and may reduce production year yields and persistence (Tesar and Marble, 1988).

In Minnesota, Hartman and Stuthman (1983) recommended a seed for oats rate of 54–72 kg ha^{-1} when used as a companion crop, compared with 72–90 kg ha^{-1} when sown alone for grain. Peters (1961) reported that oats cut for forage at the late dough stage plus a cut of intersown lucerne yielded more than lucerne estab-

Figure 3.3
Swathing oats

Figure 3.4
Cattle grazing oats through the snow in Canada. Oats were seeded in late May and swathed at the soft dough stage in September before any killing frost, and grazed through the snow in winter

lished with or without herbicides and harvested twice in the establishment year. In contrast, Brink and Marten (1986) showed that oat as a companion crop to lucerne had inferior forage quality compared with barley when the mixture was harvested in the sowing year. In California, Lanini *et al.* (1999) reported that oat intersown into an established (but declining) lucerne stand was comparable to using paraquat herbicide for weed control, with the advantage of increasing first harvest forage yield. Marshall, McDaniel and Cregger (1992) suggest that growers planning to use oats as a companion crop should use early maturing, lodging-resistant cultivars, and remove the oat forage early to favour the establishing perennial forage crop.

Swath grazing

Swath grazing of cereals is a relatively novel system for late autumn and winter grazing for beef cows, and is gaining popularity in western Canada (Alberta Agriculture, Food and Rural Development, 1998; Entz *et al.*, 2002; McCartney *et al.*, 2004b; Baron *et al.*, 2004). Late-sown cereals are swathed (Figure 3.3) in the early autumn, from heading until dough stage. The livestock then graze the swaths through the snow (Figure 3.4). This is a form of stockpiling of forage for autumn and winter grazing when conventional pastures

cannot meet the nutritional requirements of ruminants. The advantage is that the swathing consolidates the forage so that the cows can graze through the snow (Aasen *et al.*, 2002). In northeastern Saskatchewan, oats were sown in mid-June and cows grazed the swaths beginning in November, for a 48-day period. Results showed that cows on swath grazing were in similar condition to those on stored feed at the end of the grazing trial (Alberta Agriculture, Food and Rural Development, 1998). Oat CP ranged from 106 to 116 g kg^{-1} from September to January (Alberta Agriculture, Food and Rural Development, 1998). In a later plot study on swath-grazed annual crops in central Alberta, oats, barley, autumn rye and annual ryegrass were mixed with peas or barley. September DM yields (3-year mean) ranged from 7 270 kg ha^{-1} (oats+peas) to 8 795 kg ha^{-1} (oats+barley) (Aasen *et al.*, 2002), and autumn CP across sampling dates and years ranged from 109 g kg^{-1} to 192 g kg^{-1} DM. The protein concentrations of all crops at all sampling dates were more than adequate for wintering pregnant beef cows (Aasen *et al.*, 2002). In southern Saskatchewan, oats were compared with other cool season and warm season annual crops for DM yields and quality for swath grazing (Klein, 2003). In this study, it was concluded that oats were less suitable for swath grazing compared with the later maturing foxtail (*Setaria italica* L.) and proso millets (*Panicum miliaceum* L.); part of this was due to the decline in DM yields with late sowing.

ANIMAL HEALTH

Winter or grass tetany, and, in some cases, milk fever, can occur in cattle fed cereal straw or green feed such as oats as the main forage in their winter feeding programme. Winter tetany is a metabolic disease caused by lower than average blood magnesium levels. It can occur when cattle graze on cereal grains such as oats (Bohman *et al.*, 1983; Doig, Marx and Lastiwka, 2002). It is often seen in cows in late pregnancy or in the early stages of lactation. High producing cows are particularly susceptible, but dry cows and bulls are rarely affected. In western Canada, dry growing conditions and acidic soils can contribute to the accumulation of potassium in feeds, which in turn reduces the amount of magnesium absorbed from the ration (Doig, Marx and Lastiwka, 2002). Symptoms may start as nervousness, attentive ears and irritability, and, after several days, may lead to extreme excitement and violent convulsions. Prevention of this disease is through supplementation of the ration with magnesium oxide and limestone, the former mixed with grain, screenings-based supplements or silage to increase intake (Doig, Marx and Lastiwka, 2002).

Oat appears to accumulate more nitrates than other small-grain crops (Garcia, 2002). Nitrate poisoning may occur if oat has been drought stressed, or damaged by hail or frost (Aasen and Baron, 1993). The risk is increased if the soil is high in plant-available nitrogen (Hartman, 2000). However, there are very few reported cases of nitrate poisoning in western Canada (Blakley, pers. comm., 2004). Rain after a drought can increase plant nitrogen uptake and the risk of nitrate poisoning during the next four to five days. During fermentation in the silo, 40 to 60 percent

of the original nitrate can disappear, making ensiling the preservation method of choice when high nitrate levels are suspected. Supplementing the oat silage with grain at feed out will also decrease the chances of nitrate poisoning (Garcia, 2002).

DISEASES AND PESTS

A comprehensive review of oat diseases was prepared by Harder and Haber (1992), while breeding aspects have been covered by Burrows (1986). The main fungal diseases in North America are the rusts (*Puccinia* spp.) and the smuts (*Ustilago* spp.). *Septoria* leaf blight has been found to be prevalent in eastern Canada, with losses of 20 percent common in Ontario and up to 50 percent in Atlantic Canada (Clark *et al.*, 1975). Barley yellow dwarf virus (BYDV) is a serious disease of oats (Burrows, 1986). In some areas, the sowing date may be delayed because of prolonged wet weather, which makes late-sown oat more susceptible to fungal and viral diseases (Burrows, 1986).

Disease and insect pests can reduce yields when growing winter oat for forage, especially where early sowing is used. In Texas, armyworm (*Pseudaletia unipuncta* Haw.), greenbug (*Schizaphis gramimum* Rondani) and aphids such as *Rhopalosiphum padi* (L.) are common, and important primarily because of their role as vectors for BYDV (Marshall, McDaniel and Cregger, 1992). Leaf rust (*Puccinia coronata* f.sp. *avenae*) not only lowers the quality of feed, but also hastens maturity, and therefore contributes to production loss (Song, 2004). The only practical solutions are to use resistant cultivars and to sow at the recommended time for the area.

BREEDING PROGRAMMES

Cultivar development in North America has been reviewed by McMullen and Patterson (1992), and breeding strategies for spring sown oats by Burrows (1986). Breeding has largely been in the domain of public agencies, such as Agriculture and Agri-Food Canada in Ontario and Manitoba, and a large number of state agricultural stations in cooperation with the United States Department of Agriculture (USDA). Most of the emphasis is on breeding oats for grain for human consumption (Stevens *et al.*, 2002). The most critical issue relative to oat improvement is the marked decline in oat area over time, especially in the USA, and the gradual decline of oat research effort in the public and private sectors in North America (Wesenberg, 2000).

Improvement in winter hardiness is an important objective of winter oat breeding programmes in the northern and central winter oat areas of the USA. Recent additions include cv. Horizon 314, a new, full-season winter oat released by the Florida and Georgia Agricultural Experiment Stations in 1999 (Barnett *et al.*, 2002). Breeding programmes have also included improvements in yield stability, seed quality, early or late maturity, lodging resistance and disease resistance. Grain quality factors such as test weight, groat percentage and protein concentration are also important considerations in oat cultivar development (McMullen and Patterson, 1992). Breeding programmes for dual-purpose (grain and forage) oats has been ongoing in Georgia, Texas, California and Alaska. Cv. Ensiler, a tall, forage-type cultivar, was released by the University of Wisconsin in 1990

(McMullen and Patterson, 1992). Cv. ForagePlus, a tall, late maturing oat with high forage yields and which can be harvested over a longer than normal period, was released by the University of Wisconsin-Madison in 2001.

Cv. Foothill, licensed and released by Agriculture and Agri-Food Canada in 1977, is a dual-purpose forage and grain oat (Schrickel, Burrows and Ingemansen, 1992). This cultivar has reasonably good quality but very poor lodging resistance (Kirkland, 2004). Cv. Foothill is being replaced by a newer cultivar, AC Mustang, in Alberta (Hartman, 2000). This cultivar, together with a hull-less (cv. AC Belmont) oat with improved yield and disease resistance, has recently been developed in Canada (Saskatchewan Agriculture and Food, 1995). Cv. Boudrias oat is a high yielding hull-less oat cultivar developed by Agriculture and Agri-Food Canada, Lacombe, Alberta, (Figures 3.5, 3.6 and 3.7) and released in 2001 (Kibite *et al.*, 2004). Cv. AC Murphy has recently been released in western Canada as a high-yielding, late maturing forage oat (Kibite *et al.*, 2002). Cv. AC Assiniboia, with low lignin levels in the hull, is well suited for the oat-growing areas of western Canada and in particular the black soil zone of Manitoba and Saskatchewan (Abeysekara, 2003). Cv. CDC Bell was developed primarily for use by cattle producers in western Canada for annual green feed or oat hay. Cv. CDC Baler is a new forage oat

Figure 3.5
Oat plots at Agriculture and Agri-Food,Canada, Lacombe, Alberta, Canada

Figure 3.6
Oat plots at Agriculture and Agri-Food Canada, Lacombe, Alberta, Canada

that has wide leaves and produces higher energy and protein levels than other commonly grown varieties. However, it is susceptible to stem and crown rust (Quality Assured Seeds, 2004).

AREAS WHERE RESEARCH OR EXTENSION WORK IS NEEDED

As shown, the emphasis in plant breeding programmes has been towards developing new cultivars for grain for human consumption, with good agronomic and disease resistance characteristics. However, there has been relatively little emphasis on the impact of these selection criteria on the nutritional value for the animal. Animal nutritionists and the livestock industry have not always provided clear direction to plant breeders with respect to the desirable qualities of a feed oat for livestock. It may well be that it is unrealistic to expect nutritionists to speak with a unified voice as the characteristics of the ideal feed oat will differ depending on whether it is fed to horses, sheep or cattle, and whether it is fed as grain or fodder. Improved cultivars for fodder must have an ability for rapid growth, profuse tillering and remain vegetative over a longer period than grain types. They must also have leaf rust resistance since the appearance and spread of the disease coincides with the period when the crop is needed for grazing (Song, 2004). Research in North Dakota and elsewhere has shown that cultivar selection affects forage yield. Additional research, particularly at the producer level, is needed to determine the forage potential of oats in areas where it is used in livestock operations.

Pasture rejuvenation offers another possibility for the use of grazing oats. Sowing oats and other annual cereals into stands of perennial forage is a common practice in the south and southwest USA (Wedin and Klopfenstein, 1985). In Arkansas, sod-sowing annual ryegrass and rye into warm-season perennial pastures offers potential to provide high quality forage for growing weaned beef calves retained until spring (Coffey *et al.*, 2002). Grazing of these sod-sown pastures offers the potential to improve land use efficiency (Moyer *et al.*, 1995) and to improve animal gains over and above gains from cattle grazing dormant species over the winter (Wilkinson

Figure 3.7
The late Dr Solomon Kibite, oat breeder, inspecting a field of oats at Agriculture and Agri-Food Canada, Lacombe, Alberta, Canada

and Stuedemann, 1983). In a long-term pasture rejuvenation study in northeast Saskatchewan, McCartney, Waddington and Leftovitch (1999) found that growing annual cereals such as oat prior to reseeding old perennial forage pastures could be used to reduce the seed germination from the dormant grass seeds remaining in the seed bank in the old pastures. The authors suggested that after the pasture had been cultivated, oat could be grown and rotationally grazed for one or two seasons with the other perennial paddocks. This would reduce the need to lower the overall stocking rates on the entire pasture.

FUTURE ROLE OF FODDER OATS IN NORTH AMERICAN AGRICULTURE

There is limited research on forage oats in North America and most oat research is directed towards the human market. Entz *et al.* (2002) reviewed the potential of forages in the Northern Great Plains and suggest that annual forage systems including oat can fill a void at specific points in livestock operations, resulting in significant savings for the entire enterprise. Specific instances where annual crops such as oats could be valuable might be when DM production and quality in conventional pasture systems is insufficient to meet the grazing demands of the various classes of cattle. In cooler regions of North America, it is less expensive to overwinter beef cows on stored feed if they enter the winter grazing period in good body condition (Willms, Rode and Freeze, 1993; McCartney, 2003). The grazing of oats in the autumn provides a system whereby

cows can substantially improve their body condition when perennial forages are of poorer quality and limited supply. Swath grazing of oats in winter is one of the current management systems that can lower the cost of wintering cows by up to 50 percent (McCartney *et al.*, 2004b). In warmer regions, oats can be used as temporary cool season forage over the winter period when the DM of warm-season perennial forages is reduced.

New ways to divert land out of grain production are being evaluated, and grazing oat could become part of the process. With the changing farming population, an inexperienced livestock producer can initially start a grazing management system by incorporating oat pastures. Carrying beef cattle in the late summer and autumn on predominately annual pasture such as oats prior to entry into a feedlot is a means of supplying a low-cost animal to the feedlot system. As indicated earlier, grazing management systems have been developed whereby the regrowth from an oat silage intercrop system using autumn cereals can provide high quality forage for this purpose. In addition, respiratory health problems can be substantially reduced by providing this type of autumn grazing system for receiver calves from auction markets or assembly yards, rather than moving these animals directly into a confined feedlot (McCartney, 2000). An annual crop such as oats that is harvested as a grazed forage with livestock will be seen as giving added value to the grazing system. With the recurrence of drought in western Canada and the USA, producers are starting to re-evaluate the role of grazing annual crops such as oats. Hay and pasture rental costs have escalated in some regions to a point where they are no longer considered an economic option. Thus cropping systems that integrate hay, silage and autumn grazing become a viable option. Oats can be part of such a management system.

Significant improvement in forage oat yields in North America is possible with existing cultivars and management techniques, provided growers are made aware of what constitutes "good" management and the potential economic benefits. Growers need to be taught through education and demonstration that many good management practices require little if any extra monetary inputs, e.g. correct sowing time and depth. Several programmes, such as the "Oats Improvement Programme" sponsored by the Quaker Oats Company of Chicago, are designed to assist producers in the management of oats (Marshall, McDaniel and Cregger, 1992).

In general, there should be increased interest in the future for oats for grazing if the economics warrant the practice. In western Canada, one has seen general adoption of the concept of swath grazing, and new fencing and grazing management technology, with an increased interest in the potential of annual crops. There is now more information available on research and practical experience of "how to do it", which was not available years ago. This will definitely assist in the adoption and uptake of oats in grazing systems by North American cattle producers in the future.

Chapter IV
Fodder oats: an overview for South America

Luiz Carlos Federizzi and Claudio Mario Mundstock

SUMMARY

Oats were introduced to Latin America by the Spanish soon after the discovery of the continent; they are used as grain for the milling industries and as horse feed, and also as a cover crop in no-till planting systems, as a fodder for animal grazing, and for forage and silage. Oats are grown in five major environments in South America: (1) the temperate area of Argentina and Uruguay; (2) the temperate area of Chile; (3) the subtropical area of Brazil (south of 24°S); (4) the tropical area of Brazil (north of 24°S); and (5) the tropical high altitude area (Andean region, with parts of the highlands of Bolivia, Ecuador and Peru). These regions differ widely in terms of environment, crop use, major breeding programmes and area under oats. The largest area under oats is in temperate and subtropical regions, but oats as a grain crop are increasing in area and importance in all environments of South America. The cropped area is increasing every year because it is a major component in the rotation system used by farmers when they adopt the no-till system.

BACKGROUND

There are no historical data, but various oat species were probably brought to the Americas shortly after their discovery by the Spanish, who brought oats to feed their horses. Thus, oats are a comparatively old crop in South America, and *Avena byzantina* was probably the first introduced in the south of the continent, in Argentina and Uruguay; its area increased at the beginning of the twentieth century, especially in Argentina and Uruguay, where it was used for fodder and for quality grain production (Boerger, 1943: 1043).

The genus *Avena* is a polyploid series with diploid, tetraploid and hexaploid species, some of which are cultivated, while others are invaders of cultivated fields. In Latin America, all the species were probably introduced from Europe, especially the diploids (*A. strigosa*) and the hexaploids (*A. sativa* and *A. byzantina*), which are cultivated and are very important economically. *A. byzantina* and *A. sativa* have been widely intercrossed, and it is difficult to distinguish them in the current varieties, so, in this study, white oats are called *A. sativa*. *A. sterilis* is a weed in Argentina and Uruguay. Although oats are best adapted to the temperate environments of the South American continent, they are widely adapted to low latitudes and tropical and subtropical environments.

Oats are important in Argentina, Bolivia, Brazil, Chile, Ecuador, Peru and Uruguay (Table 4.1). In most countries, oats are more important as fodder for livestock in the field. In Brazil, Argentina and Chile, oats are very important as grain for the transforming industry. These countries grow the largest areas (Table 4.1). The harvested area is quite small in the Andean region, as most of the area sown is used as fodder. Data for Uruguay are the same for the last five years, implying that they are probably out of date.

TABLE 4.1
Mean values (± standard errors) for five years (1998–2002) of oat harvested area, grain yield and total oat yield in the main producing countries in South America

Country	Harvested area ('000 ha)	Grain yield (kg ha $^{-1}$)	Production ('000 t)
Argentina	327.5 ± 45	1742 ± 114	574.0 ±101
Bolivia	4.9 ± 0.46	930 ± 7.8	4.6 ± 0.07
Brazil	221.6 ± 28	1217 ± 196	274.0 ± 74
Chile	85.2 ± 6.8	3396 ± 699	292.0 ± 77
Ecuador	1.1 ± 0.19	726 ± 40.8	0.82 ± 0.16
Peru	63.6 ± 29.9	134 ± 35	8.4 ± 3.9
Uruguay	45.0	1000	45.0

SOURCE: FAOSTAT (www.fao.org – as of 20 February 2003).

Recent studies (Rebuffo, 1997) report that the area under oats in Uruguay was 65 000 ha in 1989, but then declined to approximately 36 000 ha between 1991 and 1995. Grain yields are much higher in Chile, where conditions are more favourable for oats, than in Argentina, Brazil and Uruguay. Yield differences reflect the conditions of each environment, but nevertheless yields in Argentina and Brazil are increasing compared with other countries. In South America, only Chile has been a frequent oat exporter; Argentina was a large exporter of good quality oats, but recently lost much of its market. Brazil was an importer until the end of the 1980s and now produces the oats it needs, but imports in years of poor harvest. Statistical data on crops such as oats, that in the past were less important, have to be viewed with caution, bearing in mind the great difficulty in data collection in the countries of the region.

Oats are grown in subtropical environments at the time of year when temperatures are at their lowest. White oats are grown on approximately 200 000 ha. Black oats (*A. strigosa*), a diploid species, is grown on more than 3 million hectares for soil cover or forage (Figure 4.1).

Oats, because of their multiple uses, are a technically and economically viable alternative crop in many production systems in the region. The inclusion of

Figure 4.1
*Maize growing through a bed of dessicated black oats (*Avena strigosa*) straw in southern Brazil*

Figure 4.2
A field of white oats (Avena sativa) for grain production in Brazil

oats in a rotation improves the physical, chemical and biological properties of the soil, reduces diseases and pests in other crops and provides biomass to maintain soil cover for a long time, with great reduction in weeds and soil erosion.

The main area under oats is as a cover crop to protect the soil before spring and summer crops. Black oat is mostly used. In general, no P or K fertilizer is needed and only N is added as a top dressing. White oats are grown when the end use of oats is grain (Figure 4.2), but when the end use is fodder, black oats are sown.

Where two crops a year (one in winter and another in the summer) can be grown, oats are becoming an important option for grain because they are used in no-till systems in rotation with wheat and barley before the soybean crop (Figure 4.3). Because of the large amount of biomass in the oat plant, farmers use less herbicide on soybeans (Figure 4.4) if they are preceded by oats, compared with wheat and barley.

The crop succession system in most of the region involves two crops per year (winter and summer). In South Brazil, small grains (winter crops: oats, wheat and barley) are sown from April to June (according to the end use and altitude) and harvested from October to November. When grown as a cover crop, *A. strigosa* is desiccated in August, at the beginning of flowering. Summer crops are predominantly maize and soybean, sown from September to November. Maize is


D.G COOPLANTO

Figure 4.3
A no-till system in which soybean is planted after oats have been harvested

Figure 4.4
Soybean growing in a field previously planted with oats in a no-till system

generally sown in September-October after *A. strigosa* desiccation, and harvested in April-May. Soybean is sown after the winter cereal harvest, usually in October-November. Some other crops are used, such as black beans and popcorn. Maize, sown early, can be harvested in February-March. In these cases a cover crop can be grown for two to three months, before sowing the winter crop.

The production system on small farms involves different crops. In tobacco production areas (spring and summer), *A. strigosa* is used as a cover crop, or as fodder in winter. In fruit producing areas, oats are sown between the lines as a winter cover crop. This permits nitrogen retention and better weed control, decreasing the use of chemicals.

In South Brazil, white oats are sown from the end of May to the beginning of July; they are commonly fertilized with phosphorus, potassium and nitrogen for grain production where soils are deficient in these nutrients. Generally, N is applied at sowing (20 percent) and at the beginning of tillering (80 percent).

Disease control is usual, and one or two fungicide applications are necessary to reduce leaf rust (the main disease) and *Pyrenophora avenae* (common in no-till systems). Barley yellow dwarf virus (BYDV), *Pseudomonas syringae* and *Ustilago avenae* also occur.

Insects damage oats, especially aphids and caterpillars. Among the aphids, *Schizaphis graminum* can transmit BYDV and others, such as *Metopolophium dirhodum* and *Sitobion avenae*, can occur until close to maturity.

Harvest is in October and is frequently damaged by high rainfall and humidity, which delay harvesting and cause losses from lodging and quality reduction (low test weight and increase in grains spotted by fungus).

Oats are used as a high quality grain in human and animal nutrition. A considerable part of the area sown is for autumn-winter grazing and also for hay and silage. As a forage producer, in pure stands or mixtures, oats are the most important crop in the Southern part of South America, because of the high quantity and quality of forage produced in this environment. Also, oats can be used for silage and hay in winter. Oats are used as forage for dairy or beef cattle, and on sheep farms used for grazing or making silage to be fed in combination with soybean meal or maize in winter, when native forages grow slowly. Oats can help stabilize the supply of meat and milk, with lower costs than maize silage or concentrate. Oat grain is harvested in October-November, which is the off-season for maize or soybean (harvested from February to April).

Black oats are grazed in winter under two production systems. In one, common in South Brazil, oats are sown direct into native pasture in autumn (April–May), when the growth of the original pasture is very slow. Fodder is obtained for 3–4 months, until the end of winter and beginning of spring and the re-growth of the native pasture. In the second system, oats are sown in association with ryegrass and clover, forming a typical winter pasture. Sowing is in April–May and the mixture lasts until October–November (end of spring). In both cases, complete soil fertilization is needed.

The use of black oats for grazing and in rotation with other grain crops reflects the need to increase the income of farmers and reduce production costs. It is estimated

that, for Rio Grande do Sul state, Brazil, in 2000, about 1 250 000 ha of black oats were grown for fodder (for dairy and beef cattle, and sheep) (Floss, 2001).

The system used on small farms involves growing *A. strigosa* on small areas and, instead of grazing, the plants are cut (manually or by machine) and used as green fodder.

Fodder oats are sown in autumn (April-May) and are mainly used in June and July. The seed rate is 80 kg ha^{-1} (250 seeds m^{-2}) using no-till machines. In some cases, oats can be sown direct into the native sward without soil preparation. In other cases, oats are sown direct into soybean or maize residues, also without soil cultivation.

BREEDING

Oat breeding has been going on for a long time in South America. It started with the first experimental stations in the area, namely the Instituto Nacional de Investigaciones Agropecuarias (INIA) in Uruguay, Instituto Nacional de Tecnología Agropecuaria (INTA) in Argentina, Secretaria de Agricultura do Estado do Rio Grande do Sul, in Brazil, and INIA in Chile (Boerger, 1943; Beratto Medina, 1994; Federizzi *et al.*, 1999). All varieties developed and released in Argentina, Brazil, Chile and Uruguay in the past 25 years are descended from an international programme started in 1974, with a grant from USAID, called *Breeding Oat Cultivars Suitable for Production in Developing Countries*, organized by H.L. Shands, Professor of Agronomy at the University of Wisconsin at Madison. Since 1977, the Quaker Oats Company has sponsored it, and it is now called the Quaker International Oat Nursery (QION). Currently, professors from the Universities of Minnesota and Florida prepare the nursery, which is composed of around 100 pure lines and 200 F_2 or F_3, or both, populations from crosses, including varieties from several programmes around the world. Currently, the nursery is sown at thirty locations in North and South America, Africa, the Near East, Europe, Australia and New Zealand. It has been a source of genetic diversity for several oat programmes throughout the world (Forsberg and Shands, 1986; McDaniel, 1997). Currently, six major oat breeding programmes are active in South America, which have contributed new varieties in the recent past. There is also a minor breeding effort by private companies in Argentina and Brazil.

MACRO-ENVIRONMENTS

South America has five major agronomic macro-environments, which differ with respect to crop end use, soil fertility and composition, rainfall, average temperatures, day length, humidity and growing season length. The valleys in the Andes, where oats are mostly used as a forage, is the least typical environment. Chile has the best conditions for grain production, while Argentina and Uruguay are similar and Brazil has two contrasting environments.

Temperate Argentina and Uruguay

There is a large area cropped with oats in both countries, located between latitudes 32° and 36°S. Soils are fertile, rainfall is adequate, temperatures are mild and days are long (spring to summer), providing a long growing season. Forage oats are sown at the beginning of autumn and usually grazed in winter and spring, and then

TABLE 4.2
Effect of cutting frequency on the production of autumn, winter and spring forage, hay yield, grain yield and test weight for three cultivars in Uruguay. Sowing date: 29 March 1995.

Cultivar		1095a		INIA Polaris		INIA Lê Tucana	
Number of cuts		2	5	2	5	2	5
Autumn	(t DM ha^{-1})	2.2	2.3	2.2	2.3	2.6	2.4
Winter	(t DM ha^{-1})	1.9	2.2	2.0	2.5	1.6	1.8
Spring	(t DM ha^{-1})	5.6	5.2	4.9	4.4	5.5	5.4
Hay	(t DM ha^{-1})	6.5	7.4	5.7	7.7	6.5	8.4
Grain	(t ha^{-1})	2.5	2.3	2.8	3.0	2.3	1.6
Test Weight	(kg hl^{-1})	39	41	54	53	49	47

SOURCE: Rebuffo, 1997.

the grain is harvested in summer. When farmers grow oats only for grain, planting is postponed to June–July and harvest is in January. There are several frosts during this season and the late frosts may damage oats. More than 2 million hectares are under oats (mostly in Argentina) and the cropped area is limited, since it has to compete with wheat and barley. The major problems for the crop are stem rust and crown rust. Since 1993, stem rust has been endemic early in the season (May) or in November and December, with severe damage to yield and grain quality.

The old variety Suregrain, introduced in the 1960s, is the most important for forage in Argentina. It is grown on a very large area of the Argentinean pampas (more than 2 million hectares). Forage cultivars have recently been released, such as Millauquén Inta (1987), Cristal Inta (1990), Bonairense Payé, Máxima Inta, Bonairense Inta Calen and Bonairense Inta Maja (2000). Most cultivars are very similar, but Calen and Maja have very good resistance to stem rust, which has been the most important disease problem in terms of forage; yields are very similar those obtained by Rebuffo (1997) and reported in Table 4.2.

In Argentina, some cultivars are specifically for grain. The more important ones are UFRGS 16, Maja, Calen and Bonairense Payé. UFRGS 16 is a Brazilian cultivar that is resistant to all races of stem rust in the region, and has been grown in Argentina for the last five years, with very good grain and milling yield.

In Uruguay, oats are mainly used for grazing. In the dairying regions they are sown in January and February, but in the beef region oats are sown later (March to May) (Rebuffo, 2001). The period of use is 6 to 9 months, and because of this long cycle, high-biomass-producing varieties should be available. In spring, part of the oats are harvested for hay and silage and 10–25 percent for grain (Rebuffo, 2001). Growth habit and sensitivity to lodging and leaf rust are limiting factors for grain production in most of the cultivars used. The most important variety is 1095a, which is an *A. byzantina* type released in the 1930s. More recently, two new cultivars have been released: INIA Polaris and INIA Lê Tucana, with better resistance to crown rust and very good yields (Table 4.2).

Data obtained by Rebuffo (1997) (Table 4.2) in Uruguay shows the potential for forage production in different seasons of the year in this environment.

There are three major breeding programmes in the region.

INTA – Barrow Chacara Experimental Station (Argentina)

This is one of the oldest oat breeding programmes in South America, and until 1990 its major goal was to release varieties for forage and then grain harvest. The main objectives are (Wehrhahne and Carbajo, 1997): develop new cultivars with higher yield potential (forage or grain, or both); increase adaptability to different regions; improve grain quality; increase resistance to crown and stem rust; increase tolerance to frost damage; and improve tolerance to aphids. The programme relies on introduction of material from the QION and has recently released two new grain-type cultivars with resistance to stem rust.

INTA – Bordenave Experimental Station (Argentina)

This Station was created in 1927, and the first experiments with oats were reported in 1934. All cultivars released by this programme have been dual-purpose (forage and grain). The most successful variety (Suregrain) was introduced in 1969 and occupied more than 90 percent of the oats area in the 1980s (Tomaso and Bucar, 1994). The main objectives are to improve forage and grain production and increase resistance to crown and stem rust. All cultivars released so far are more suitable for forage production and are susceptible to crown and stem rust.

INIA – La Estanzuela (Uruguay)

This oat breeding programme started very early in the twentieth century. Because, historically, oats have been a multipurpose crop in Uruguay, especially forage production for autumn and winter, most varieties are old and have these characteristics. Recently released cultivars are better grain producers (Rebuffo, 1997). The main objectives are to: develop new cultivars with more forage and grain production; develop cultivars with different morphological characteristics; increase resistance to crown and stem rust; and increase tolerance to BYDV.

Temperate Chile

Chile has an excellent area for small grains, with favourable environment and soils. About 8 percent of the area devoted to grain is under oats, which, in Chile, are grown between latitudes 37° and 43°S, in fertile soils, with mild temperatures and long days, that results in a long, favourable growing season (up to 6 months). Oats can be sown in May or mid-August and harvested in January or February. Because of the low humidity, diseases are not as serious as in other regions of oat production in South America, but crown rust (Figure 4.5) and BYDV are present in most years. Yields are generally high and grain quality and milling yield excellent. In some years, low rainfall in November-December reduces yield and grain quality.

In Chile, 80 percent of the area under oats is for grain, but only 10 percent of that is used for industrial purposes. The remaining 90 percent is for livestock feed on the farm. In this favourable environment, European varieties were introduced with favourable growth habit, agro-ecological adaptation and high yield potential. Since 1975, new introductions have been made from USA through the QION programme. This newly introduced and adapted germplasm has brought new traits, such as resistance to lodging, good agronomic type and resistance to crown

Figure 4.5
Varieties of oats susceptible (in front) and resistant (behind) to crown rust

and stem rusts. This combination of traits resulted in high yielding cultivars with good grain quality (Beratto Medina, 1997). Oats are a very important crop, and one that competes for land with barley and wheat, and is used in the rotation to reduce or avoid the root diseases of the other cereals.

There is one major breeding programme: Instituto Nacional de Investigaciones Agropecuarias (INIA), which started in 1965 at the Experimental Station of Carrilanca, with several cultivars released for all the Chilean environments. It focuses on breeding oats with excellent milling yield, and the main cultivars in use by the farmers are Neptuno Inia, Urano Inia and Nehuén. The main objectives are to: introduce and develop oat cultivars with high yield potential; improve the milling yield and chemical composition of oat grain; introduce resistance to major diseases; and improve the agronomic characteristics of the oat plant (agronomic type, resistance to lodging and short plant height).

Subtropical area (south Brazil)

Brazil has two major areas of oat production: subtropical and tropical. In both environments, oats are expanding in area, even when competing with wheat and barley. The southern (subtropical) region is between latitudes 24° and 32°S, with soils of average fertility and high levels of aluminium. Good solar radiation, non-limiting temperatures and adequate rainfall in all months allows intense soil use throughout the year.

The climatic conditions make it possible to grow two crops a year: one in winter (generally a small grain), and a summer crop, typically maize or soybean. In this area, rainfall ranges from 1 100 to

TABLE 4.3
Grain yields (kg ha⁻¹) of several oat lines in tropical and subtropical regions of Brazil, with and without fungicides

Line	Tropical region		Subtropical region	
	without fungicide	with fungicide*	without fungicide	with fungicide*
UPF 16	2 865	3 446	2 766	–
UPF 17	2 620	2 727	2 387	3 895
UPF 18	2 970	2 969	3 356	3 570
UPF 19	3 393	3 446	2 799	–
UFRGS 14	2 863	3 708	2 631	–
UFRGS 16	2 608	2 746	3 020	3 567
UFRGS 17	3 185	3 741	2 632	3 286
UFRGS 19	3 617	3 619	3 027	3 479
URS 20	3 233	3 030	2 897	4 169
URS 21	3 544	3 514	3 558	–
OR 2	3 617	4 095	3 316	–
MEAN	3 137	3 367	2 944	–

Notes: * With two application of fungicide tebuconazole (0.75 litre ha⁻¹) for crown rust control.

1 500 mm, well distributed throughout the year, humidity is usually very high during most of the season, and in the coldest months days are short and the average temperature varies from 12 to 15°C. The growing season is less than 150 days. The major crop rotation used by most farmers is half soybean and half maize in summer, followed in winter by one-third of the area with wheat, barley or oats, and two-thirds with black oats. The black oats are sown in May and desiccated with herbicide by flowering time (usually in September), when maize is sown. The market prices of wheat, oats and barley will define the area of each crop. Most farmers avoid growing wheat or barley two years in succession because of disease problems, and oats are used in this case. Oats can be a very good alternative crop for poor farmers because it grows and develops well on poor soil and is tolerant of aluminium toxicity. Because of its several uses, in mild winters (when there is enough forage from native species) the oat crop can be allowed to mature and the grain harvested and used for animal feed just when the price of maize is usually high. Farmers growing black oats before soybeans are switching to white oats and use their grain for animal feed on the farm, or sell if prices are favourable.

Diseases are widespread, especially crown rust, with several different and virulent races occurring most years, and with high probability of rainy days at harvest time. Thus, yields are variable among years and there is a large genotype × year interaction.

Currently, the grain producing cultivars available to farmers are: UPF 15, UPF 16, UPF 18, UPF 19, UPF 20, UPFA 22, UFRGS 14, UFRGS 15, UFRGS 17, UFRGS 19, URS 20, URS 21, URS 22, OR2, OR3, OR4, FAPA 4, FAPA 5, FAPA 6, CFT 1, CFT 2 and IAC 7. Yields obtained in tropical and subtropical areas (average of two sites over five years, 1997 to 2001) from the most important varieties are shown in the Table 4.3, and the major traits in Table 4.4.

Because of crown rust, cultivars have a very short life in the farmer's fields and new ones need to be released every year.

TABLE 4.4
Agronomic characteristics of several oat lines currently in use in south Brazil

Line	Test weight (kg hl⁻¹)		1000-grain weight (g)		Plant height (cm)	Emergence to flowering (days)	Reaction to crown rust	Reaction to stem rust
	-F	+F	-F	+F				
UPF 16	45	50	32	34	97	98	S	S
UPF 17	43	48	34	38	94	98	S	S
UPF 18	48	51	32	33	120	103	MR	S
UPF 19	50	51	33	35	111	99	S	S
UFRGS 14	45	49	36	38	98	98	S	S
UFRGS 16	47	49	32	33	110	102	MS	R
UFRGS 17	49	52	32	35	106	97	S	S
UFRGS 19	54	55	30	30	94	93	S	MR
URS 20	52	53	33	34	101	98	MR	R
URS 21	52	53	31	32	111	93	R	MR
OR 2	49	49	26	27	100	100	R	MR

KEY: -F = without fungicide; +F = with fungicide; S = susceptible; MS = moderately susceptible; R = resistant; MR = moderately resistant.

Environmental conditions are ideal for rust spread (high temperature and humidity) and oats are present in fields all year round. The pressure by the fungus is therefore more intense than in any other region of the world (Stuthman and Federizzi, 1997).

Two good, important traits present in Brazilian oat cultivars are their ability to provide good grain filling in warm environments, and very good tolerance to high soil aluminium levels (Sanchez-Chacon, Federizzi and Milach, 2000).

The main variety for forage and soil cover for no-till planting is called *preta comum*, or "common black". It is an old *A. strigosa* variety selected from an even older one called Saia, introduced to the State of Rio Grande do Sul in the early 1940s and of unknown origin. It is grown on more than 3 million hectares as a cover crop in autumn and winter. New cultivars have been released in more recent years. Cv. São Carlos is an *A. strigosa* variety better adapted to the tropical region of Brazil. Another *A. strigosa* – cv. IAPAR 61 – was released in 1993 and quickly became the most popular soil cover variety. It has a long cycle (134 days from emergence to flowering) and some cold requirement for flower initiation, so its flowering is delayed in the more tropical areas. FAPA 2 is another forage variety of *A. sativa*, with good dry matter production in both oat environments of Brazil.

Data on the production of forage for three cultivars and their main agronomic traits are presented in Tables 4.5 and 4.6.

Data obtained by Floss (2001) over a ten-year period at Passo Fundo (RS) with *A. strigosa* (average of several genotypes every year) (Table 4.7) shows the usual variation among years normal in the subtropical environment, with years of excellent development and years of poor crop development and growth.

TABLE 4.5
Forage production from three oats (in southern Brazil)

Variety or line	Cut for forage DM[1] (kg ha⁻¹)	As a cover crop [2] (DM; kg ha⁻¹)
FAPA 2	4 936	7 637
IAPAR 61	4 581	8 359
Preta comum	–	6 986

SOURCES: (1) Scheffer-Basso *et al.*, 2002a. (2) Scheffer-Basso *et al.*, 2002b.

TABLE 4.6
Days to heading, height, 1000-grain weight and reaction to crown and stem rust of three oat varieties at Passo Fundo, Brazil

Variety or line	Heading (days)	Height (cm)	1000-grain weight (g)	Reaction to crown rust	Reaction to stem rust
FAPA 2	139	125	27	MS	MR
IAPAR 61	134	145	15	MR	MR
Preta comum	98	135	21	MR	MS

KEY: MS = moderately susceptible; MR = moderately resistant.
SOURCES: Scheffer-Basso *et al.*, 2002a, b.

TABLE 4.7
Biomass and dry matter yield of *A. strigosa* at Passo Fundo, Brazil in different years

Year	Green biomass (kg ha^{-1})	Dry matter (kg ha^{-1})
1991	32 568	8 550
1992	33 088	8 002
1993	22 409	5 214
1994	20 182	5 500
1995	20 064	5 385
1996	28 293	7 509
1997	26 630	6 657
1998	27 386	6 018
1999	36 202	7 402

SOURCE: Floss, 2001.

The popularity of black oats as a winter crop is attributable to a combination of characteristics: low seed price and favourable conditions for seed production; low production cost compared with other green manures; high carbon : nitrogen ratio, ensuring high biomass necessary for the no-till production system (over 6 t ha^{-1}); hardiness compared with other cereals; better aluminium tolerance; better growth and development in poor soils; a very aggressive root system that helps to improve the physical properties of the soil; better tolerance to root diseases than wheat and barley; and better resistance to trampling.

Silage is one way of using white oats (*A. sativa*), but is not common. Cropping techniques are similar to those adopted for grain cultivation. The most favourable cutting period is flowering; the crop is wilted to eliminate excess water, and high yields of good quality are obtained (Table 4.8) (Sartoretto *et al.*, 2002).

There are two main oat breeding programmes in the region.

University of Passo Fundo – UPF

This programme started in 1977, and is based at the University of Passo Fundo, in the city of Passo Fundo in the State of Rio Grande do Sul. It has been very successful in releasing cultivars with excellent yield potential and grain quality. Initially, the programme relied exclusively on germplasm introduced through the QION, but, in the 1990s, crosses made by the programme were of more importance. There are six cultivars recommended for all oat producing regions. The main

TABLE 4.8
Silage dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) acid detergent fibre (ADF) and total digestible nutrients (TDN) for black and white oats, expressed as percentage of DM

	DM (kg ha^{-1})	CP (%)	NDF (%)	ADF (%)	TDN (%)
Black oats	6 080	10.0	63.8	45.0	56.3
White oats	4 604	9.2	64.2	39.5	60.2

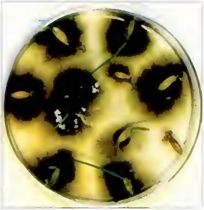

Figure 4.6
*The leafspot fungus (*Pyrenophora avenae*) growing out from infected oat grains in culture*

objectives of the programme are to: develop cultivars with high yield potential and adaptation to Brazilian environments; create cultivars with better grain quality; increase tolerance to crown and stem rusts; increase resistance to BYDV; and increase tolerance to aluminium.

Federal University of Rio Grande do Sul – UFRGS

The programme at UFRGS started in 1974 and is at the College of Agronomy in Porto Alegre. The primary goals of the University have been to train students in plant breeding (under- and postgraduate levels) and to do basic research on small grains. Because of the needs for new oat varieties, the programme in the 1980s was devoted more to oats than wheat, and now is devoted exclusively to oat breeding. Nine cultivars from the programme are currently being used by farmers. A major characteristic of the programme is its strong support from genetic studies, most of them done by graduate students. The main objectives are to: develop oat germplasm with higher yield and grain quality, and adapted to subtropical conditions; modify the oat plant to become a grain producer (better agronomic type), with short plant height and resistance to lodging; create cultivars with early maturation; increase resistance to crown and stem rusts, using partial resistance to crown rust; increase resistance to leafspot (caused by *Pyrenophora avenae*; Figure 4.6); and carry out genetic studies on traits of agronomic importance.

Tropical Brazil

The tropical area lies between latitudes 20° and 24°S, at less than 900 m above sea level. It is a new area, where oats are being grown with relative success. Soils are of medium fertility, without aluminium, and temperatures are high and days are shorter, with a growing season of less than 120 days. Yields are variable, with major differences between years. Oats are sown in March and harvested in August, when humidity is low and there is no rain, which provides good conditions for an excellent quality grain harvest. The major problems are crown rust, low rainfall, and frost damage in years of more severe winters. This environment is also covered by the two breeding programmes discussed under subtropical Brazil, and the cultivars used are the same.

Tropical high-altitude area (Andean)

The most tropical area where oats are grown in South America is in valleys in

the Andes of Bolivia, Ecuador and Peru. For this environment (tropical high altitude), oats are grown as a dual-purpose crop (both forage and a source of grain for animal feed). Oats in this area are grown at over 2 600 m elevation but very little published information could be found at the time of writing.

In Peru, oats are grown at between latitudes 7° and 8°S, above 2 700 m and with annual precipitation of about 700 mm. Oats are sown for grazing and forage production during October–December. The oat season is very long (up to 7 months) and most cultivars are introductions from Europe. They are very tall, and suitable for forage production. The main cultivars used in the region are Vilcanota, Mantaro and Pastos (*A. strigosa*).

In Ecuador, oats are grown at elevations of over 2 600 m, mostly for forage. Sowing is in December–January in higher zones, and in February–March at elevations below 2 800 m. The season is very long, taking nearly 200 days to complete full crop maturation, and grain yields can be more than 3 t ha^{-1}. Oats occupy a small area because they compete for space with wheat and barley. The main problem in this region is stem rust caused by *Puccinia graminis* f.sp. *avenae*, especially in the hottest and most humid months close to grain maturation. Another problem is the green cereal aphid (*Schizaphis graminum*) that transmits BYDV, causing plant yellowing and death.

There are at least two experimental stations selecting lines adapted for this environment.

In Ecuador, the Estación Experimental de Santa Catalina (an INIAP station) has released cultivars INIAP-82 and INIAP-Monjarda 90. Both cultivars are adapted to more than 2 500 m elevation and a season longer than 190 days, and provide very good forage production (>30 t ha^{-1}) and good grain yield (1 500-3 800 kg ha^{-1}) (Fuentes and Cazar, 1990).

In Peru, the Estación Experimental Bãnos del Inca has been working with oats and has released a variety of *A. strigosa* named Pastos, introduced from Europe (Hungary and France). Also, there is information that basic seed was been produced for two oat varieties, Vilcanota and Mantaro 15.

RESEARCH

Brazil

Most oat research is devoted to grain production, and is carried out by various institutions and involves activities ranging from biotechnology to the development of new cultivars and agronomic practices suited to the various oat-growing environments. More than 100 papers are presented every year at the Brazilian Oat Meeting, and several graduate programme dissertations have been presented that focus on the oat crop. In Brazil, oat research at Universities allows training in formal graduate studies or through short courses or visits.

As far as *A. strigosa* is concerned there is no true breeding programme in Brazil, and there is a need to start effective breeding in order to obtain better cultivars. The current variety of black oat, used extensively as a forage and cover crop, is very susceptible to crown rust and has been mixed with several other black oat varieties. There is also a need for a better extension programme, since most agronomists working with farmers and cooperatives know little about the crop. In Brazil, grain and animal production are

carried out in different regions, and only recently have grain producers begun to integrate on-farm grain production with livestock production. Oats might increase in importance for forage in the grain growing area.

Argentina

Oat research has almost disappeared in Argentina. The very few programmes that were in place did not handle the stem rust epidemic properly at the beginning of the 1980s and no cultivars with good resistance were developed. Only the programme at Barrow is now developing new oat cultivars with resistance to stem rust. Argentina urgently needs to add well-trained young researchers, especially in breeding for forage and grain, and in plant pathology.

Chile

The single oat breeder in Chile is near retirement, and new staff are needed, in view of the national importance of the oat crop.

Regional cooperation

Oat researchers in Argentina, Brazil, Chile and Uruguay are linked through the QION, and also through meetings and frequent visits, so information and breeding material flow freely in the region. For the Andean region, a link is needed between the researchers working there and other breeders in South America, so that they can share experiences and breeding material.

Chapter V
Fodder oats in the Maghreb

Al Faïz Chaouki, Mohamed Chakroun, Mohamed Bechir Allagui and Adnane Sbeita

SUMMARY

In the Maghreb, oats are grown mainly for animal feed, on about a half a million hectares, pure or mixed with vetch. The main use is as hay, fed to livestock when green forage is not available (summer and early autumn). Some farmers make oaten hay for sale as a cash crop, especially in drought years. Oats are sown in the autumn, in rotation with wheat, food legumes or fallow. Plant breeding has had an important role in improving material from other countries to fit the agroclimatic conditions of the south Mediterranean. With farmers beginning to grow more forage for their livestock, interest in oats is growing, replacing use of fallow and rough grazing, the area of which is declining steadily.

INTRODUCTION

The Maghreb – from the Arabic for "west" – is that region of Africa bordering the Mediterranean Sea, but excluding Egypt. It comprises Morocco, Algeria, Tunisia and the Libyan Arab Jamahiriya. It stretches from 13°W to 25°E and from latitudes 19°N to nearly 38°N. The Maghreb countries were under various regimes of colonial rule over a long period, including Roman and Ottoman occupations. For part of the nineteenth and twentieth centuries, Algeria, Morocco and Tunisia were under French control, and the Libyan Arab Jamahiriya was occupied by Italy in 1912. Algeria regained its independence in 1962, the Libyan Arab Jamahiriya in 1951, Morocco in 1956 and Tunisia in 1957.

The Maghreb covers over 4 700 km^2, but well over 80 percent of the area is desert. Its relief is in two broad categories: the Atlas and the Sahara. The Atlas mountains are a group of related ranges stretching from western Morocco to northeastern Tunisia; the Atlas system runs southwest to northeast roughly adjacent and parallel to the coastline. The northern mountains capture most of the precipitation, so the agricultural lands are limited to the north. The climate of the agricultural areas of the Maghreb is typically Mediterranean, with hot dry summers and rain occurring in the cool season. Temperature is governed not only by altitude but also by the degree of continentality; inland stations have relatively hotter summers and colder winter than areas that benefit from the buffering effects of the sea.

Oats (*Avena sativa* L.) are the most important sown forage in the rainfed area of the Maghreb region. European cultivars were introduced in the colonial period, which lasted from the end of the eighteenth century until 1960, and were used initially as a companion crop for vetch. Since their introduction, oats have shown good adaptation to some ecological zones of the region and are widely grown and used as a dried fodder, eaten fresh by livestock or for sale (hay) as a

cash crop. The total area under oats in the Maghreb is estimated at about half a million hectares. The area sown to oats alone is increasing continuously, while that of oats mixed with vetch is declining. There are two explanations for this trend: (i) the high cost and the non-availability of vetch seed; and (ii) the complicated crop management of the mixture (crop competition, fertilization, weed control, etc.).

Research on oats started a few years after their introduction, and consisted of trials with European material. Then breeding programmes began, particularly in Algeria and Morocco, since the introduced European cultivars were not adapted to local conditions. After independence, oat research stopped for quite a long time. Farmers used varieties selected during the colonial period, and some imported from Europe and Australia. Breeding programmes were started in Tunisia (1975) and Morocco (1981), which have produced seven new cultivars in Tunisia and 11 new cultivars in Morocco.

OATS IN MOROCCO

Oats (*A. sativa*) were introduced to Morocco by the French at the beginning of the twentieth century. At that time, most forage came mainly from natural grazing, stubbles, fallow, lucerne and barley. There were several reasons for the success of oats, according to Grillot (1938). It was a crop that French farmers knew well, and yielded several products, such as grain and forage, or could be mixed with vetch. It was also in particular immune to the Hessian fly (*Mayetiola destructor*) that caused serious damage to other cereals.

In Morocco, oats are grown essentially in rainfed areas, almost exclusively for forage, mainly hay, alone or as a mixture with annual legumes, mainly vetch. The current areas are about 70 000 ha for oats and 50 000 ha for oat+vetch mixture. In recent years, there has been an increase in oats in pure stand and a decrease in use of mixtures (Figure 5.1). This is due to a change in farmer attitude regarding the more difficult cultural practices of mixtures, reflecting non-availability of adapted and synchronized varieties; difficulties in weed control (Figure 5.2); and the high cost and the scarcity of vetch seed.

Recent statistics show that oats are the third forage crop, after lucerne (*Medicago sativa*) and barley (*Hordeum vulgare*) (Figure 5.3), but the statistics do not distinguish between barley used as green forage or harvested for grain. The latter probably dominates, since barley is used for human food and is the main concentrate in animal feed.

Main cultivars

The first varieties from Europe did poorly in Morocco. Thereafter, Grillot (1938) introduced *byzantina* types from Algeria, which constituted the genetic basis for the first locally selected varieties. Some of these varieties are still grown, such as cvs Roummani, Zhiliga and Tiddes, but they are now very susceptible to the common diseases and cannot cover all the potential ecological zones for oats. Locally produced oat seeds are mainly a mixture of these varieties, with some imported admixtures.

The oat breeding programme resulted in the selection of 11 cultivars, which were registered in the national catalogue – an official listing where any new crop cultivars have to be registered before they can be sold to farmers in Morocco. Some

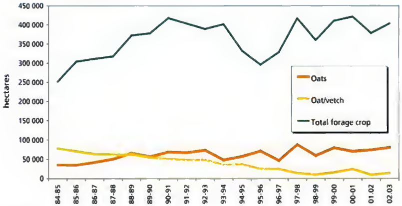

Figure 5.1
Evolution over 18 years (1984/5 2002/3) in the areas sown to oats alone and to oats+vetch mixtures

Figure 5.2
A weedy oat field (in background) in Morocco

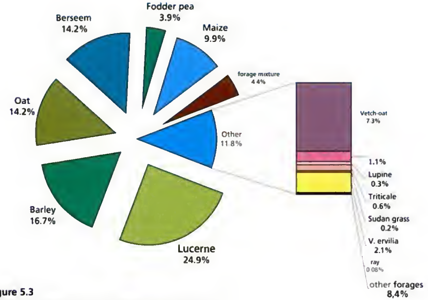

Figure 5.3
Relative importance of forage crops in Morocco.
SOURCE: MADREF.

characteristics of the registered oat cultivars are summarized in Table 5.1.

Moroccan seed companies currently sell most of these cultivars. INRA produces the first seed generations. In addition, other cultivars are sold by some foreign seed companies after their approval and inscription in the National cultivars catalogue, which means that these cultivars yielded more than the control in two-year trials at a range of sites, conducted by the Official Catalogue Service (Table 5.2).

Breeding

Following independence, there was a break of nearly 20 years in the breeding programme, due to changed research priorities. In the early 1980s, INRA restarted oat selection, mainly using material from the Quaker Oats Company and USA universities (Illinois and Minnesota).

The programme aims to select cultivars (Figures 5.4, 5.5 and 5.6) adapted to three ecological areas (favourable rainfed; semi-arid; and highlands) and uses the following criteria (Al Faïz, Saïdi and Jaritz, 1997):

- high yield of either forage or grain;
- tolerance to the most important diseases of oats in Morocco: rusts, and Barley Yellow Dwarf Virus (BYDV);
- resistance to lodging and shattering; and
- earliness for semi-arid areas, mid-earliness to late for favourable rainfed areas, and late for the mountains.

Morocco is a centre of genetic diversity of the genus *Avena*. According to the morphological species concept, 32 species have been recently named (Leggett, 1992), while earlier, Ladizinsky (1995) defined 13 species, using criteria for biological species. To make use of some native

TABLE 5.1
Some INRA-selected oat cultivars and their agronomic characteristics

Cultivar (year registered)	Cycle	Experimental yields (t ha⁻¹)		1000-grain weight (g)	Straw characteristics		Diseases under natural infection [1]			Lodging[1]
		DM	Grain		Height	∅	Crown rust	BYDV	Powdery mildew	
Abjaou (2001)	early	11.2	3.9	31	tall	medium	R	T	PS	T
Al Aâz[2] (2003)	early	-	3.2	28	medium	medium	PR	T	PS	T
Amlal (1996)	mid-early	9.9	2.6	34	tall	medium	R	PS	PS	PS
Essalam (2003)	late	13.2	3.9	34	tall	medium	R	T	PS	T
Faras (1989)	mid-late	8.3	3.4	26	semi-dwarf	high	S	PT	PS	T
Ghali (1989)	late	8.9	3.4	26	medium	high	PS	S	PS	T
Nasr (1996)	mid-early	9.7	2.9	31	medium	medium	PR	PS	PS	S
Rahma (1990)	mid-early	8.2	3.5	27	medium	medium	PS	S	PS	PS
Romani (1982)	early	7.1	2.1	45	tall	high	S	S	S	S
Soualem (1989)	mid-early	8.6	3.1	29	medium	medium	PS	S	PS	PS
Tislit (1993)	mid-early	7.2	4.3	34	semi-dwarf	high	S	PS	S	T
Tissir (1994)	mid-early	10.7	5.3	27	tall	medium	R	PS	PS	PS
Zahri (1993)	mid-early	6.3	3.8	27	medium	medium	R	PS	PS	T

KEY: ∅ = diameter. (1) S = susceptible; PS = partly susceptible; R = Resistant; PR = partly resistant; T = tolerant; PT = partly tolerant. (2) Naked oats.

TABLE 5.2
Registered oat cultivars from foreign seed companies

Cultivar name	Company	Registration year
Avon	Seed Co Australia	1990
Caravelle	Claeys Luck	1982
Echidna	Seed Co Australia	1991
Madone	Ringot-Serasem	1988
Margame	Ringot-Serasem	1988
Mortlock	Seed Co Australia	1991
Swan	Seed Co Australia	1990
Winjardie	Seed Co Australia	1996
Pallinup	Seed Co Australia	1998

wild oats, particularly the tetraploids *A. murphyi* and *A. magna,* which seem to have great potential as genetic resources (protein content and disease resistance to rust, powdery mildew and BYDV), a large programme was started that aims to develop these wild Moroccan tetraploid oats as domesticated crop plants.

Diseases

As in other parts of the world, oats are subject to many diseases in Morocco; the most serious are:

- Barley Yellow Dwarf Virus (BYDV), particularly serious during drought;
- Crown rust, caused by *Puccinia coronata* f.sp. *avenae*; and
- a powdery mildew, caused by *Erysiphe graminis,* which has caused severe damage during cool and wet conditions.

Less serious disease problems include:

Figure 5.4
Oat variety trial at Laradi, Morocco

Figure 5.5
Farmer variety trial with new oat varieties, Morocco

Figure 5.6
Discussing a trial on extension plots, Morocco

- Stem rust, caused by *Puccinia graminis* Pers. f.sp. *avenae*, which tends to cause damage of similar extent to crown rust;
- Septoriosis, caused by *Septoria avenae*. Despite its devastating effect when reported, it is uncommon in Morocco; and
- Helminthosporosis, caused by *Helminthosporium avenae*, which is present but does not occur on a serious scale.

Oat production and animal feeding systems

At the national level, green forage yields vary from year to year. They are usually very low. Yield estimates are around 10 t ha^{-1} of fresh material, which means less than 3–4 t DM ha^{-1} (MADREF, 2002). Their contribution to total forage production is less than 10 percent. Experimental data show that potential yields are much higher, and some plots have reached 15 t DM ha^{-1} in favourable years with some disease-resistant and productive genotypes.

Oaten hay is fed to livestock during the lean season, which starts in June and lasts until November. Oat hay forms 15–20 percent of the ration; the rest is mainly concentrates (Arbaoui, 1995). The livestock system most concerned with oat hay is semi-intensive dairying and fat cattle production, in the favourable rainfed area.

In some favourable areas (rainfall >800 mm), in the northwest of Morocco, with 15 percent of all the oat area, oats are mown or grazed green and used fresh. In

most cases, farmers stop mowing in time to save late growth for haymaking. In this case, oat hay and fresh oats contribute 60 percent of the total ration (Ayadi, 1994).

Problems in oat production in Morocco

In Morocco, oats are mainly grown by stock raisers in the favourable and mountainous rainfed areas, and are usually grown for on-farm use, rarely for sale. Such farmers, who generally own 10 ha or more, grow oats in pure stand or mixed with vetch, mainly for hay, which is fed in summer, when no other forage is available. Oats are grown in rotation with wheat or food legumes. With the recent decrease in food legume area, the tendency is towards biennial rotation with wheat. However, farmers do not give oats the same attention as wheat, which is why oats in Morocco do not yield their full potential. Some major problems are summarized below.

Inappropriate cultural practices

Generally, farmers who grow forages use them in a rotation after wheat and before a food legume. Where farmers grow forages, there is little or no fallow land, since fallow used to be considered a forage resource.

Farmers use a high seed rate, generally exceeding the recommended dose, which is about 100–120 kg ha^{-1}; some use up to 200 kg ha^{-1}. This may give finer-stemmed forage but reduces tillering, increases the risk of lodging and raises costs due to the high price of seed.

Farmers sow oats late since forages are sown after what are considered important crops, such as cereals and food legumes (*Vicia faba*, *Cicer arietinum* or *Lens esculentum*). The consequence is reduced yield and the impossibility of using oats for both grazing in winter and hay in spring. This explains in part why oats are not grazed or cut before maturity. Late sowing makes oats less competitive with weeds, which are a great problem, because very few farmers use herbicides on forages.

Inadequate nitrogenous fertilizer

Farmers generally pay little attention to forage crops. The reasons are the high fertilizer cost and a lack of demonstrations to convince them of the benefits. Oats, like other grasses, respond positively to nitrogen. By omitting such practices, farmers do not profit fully from the oats' potential.

Little use of certified seeds

In Morocco, seed technology is well organized. Government controls the production chain of the seed subsector, from the registration of new cultivars up to the sale of certified seed. Despite this well-established system, most farmers use uncertified seed and certified seed comprises only about 10 to 20 percent of that sown. This is mainly due to competition from the common seed trade, which seems to be more profitable. The government sets certified seed prices but the demand for oat seed exceeds supply. Seed producers, who are generally specialized seed growers, are more interested in selling their product as ordinary seed than as certified seed.

Hay

The main use of oats in Morocco is for hay (Figure 5.7). Farmers are quite well equipped with the necessary modern machinery; this consists of a disc mower

Figure 5.7
Oat hay making in Morocco

and sometimes, although rarely, a flail mower, swathe-handling machinery and pick-up baler. In general oats for hay are cut at the late dough stage, and sometimes even at the beginning of grain maturity. Furthermore, the harvested crop is left in the field for a long time, exposed to high temperatures and possible spring rain. Hay thus prepared will have reduced nutritive value.

Dual-purpose oats

Oats grown primarily for hay, silage or grain could be grazed beforehand in winter, as is done in other Mediterranean countries. In Morocco, and for most of INRA's cultivars, grazing or mowing oats at the proper growth stages does not affect the final dry matter or grain yield significantly, particularly when rainfall is adequate after grazing or mowing (Dönges-Orth, 1996). Currently, except for some limited areas in the northwest, farmers do not take advantage of this, whereas those who grow barley as forage do so widely. Barley, as a dual-purpose crop (green forage and grain) is grown in the semi-arid zone (less than 350 mm annual precipitation), and also in the mountains and a few irrigated areas. Forage barley is never made into hay. It is generally grazed or cut to feed animals in autumn and early winter

Silage

Despite their relatively low crude protein content, Koller (1996) demonstrated that INRA's oats cultivars are well suited for

TABLE 5.3
Average DM yield of oats under different nitrogen fertilization regimes in two contrasting years (drought vs rainy) at El Koudia, Morocco

Year	Rainfall (mm)	Water reduction compared with the long-term mean (%)	Average (t DM ha⁻¹)	Yield Relative to the control (%)			
				0[1]	60[1]	120[1]	180[1]
1990/91	433	9	9.24	100	146	180	194
1992/93	229	52	3.72	100	90	96	93

KEY: (1) Nitrogen fertilizer rates in kg ha^{-1}.
SOURCE: Jaritz, 1994

silage. The small number of farmers who make silage mainly use maize and very rarely use oats. In Morocco, silage making is not well developed because of small farm size; high cost of machinery; the complicated nature of silage making; and the limited educational level of most farmers. Hay is preferred for its simplicity.

Nitrogen fertilization

In Morocco, the effectiveness of nitrogen fertilization depends on the weather (Table 5.3). In drought years, nitrogen has no effect on oat yield and farmers should reduce nitrogen by at least half (Al Faïz, Saïdi and Jaritz, 1997). In rainy years, farmers should apply enough nitrogen, with split applications to avoid lodging and waste by leaching.

Furthermore, to improve the quality of oat forage (protein content), nitrogen fertilization should be increased, particularly for the late cultivars that are recommended for the favourable areas (irrigated areas and high rainfed area (>600 mm y^{-1})).

Research needs

Morocco has many indigenous oat species. With recurrent drought, overgrazing, excessive use of herbicides on cereals and urbanization, many habitats of wild oats are threatened. The genetic resources reservoir should be preserved by developing either *ex situ* or *in situ* conservation. This could be achieved by developing a real gene bank and declaring threatened natural habitats as protected areas. There are many wild oat accessions, collected in the past, that have yet to be entirely evaluated for valuable traits, including biotic and abiotic stress resistance, quality, etc. Research is also needed to improve oat seed multiplication.

Participatory plant breeding

One identified need is that of development of participatory plant breeding coupled with on-farm seed production. Currently, certified oat seeds are used on less than 10–20 percent of oat-sown areas. The remaining area is sown with seed produced on-farm, called "standard seed", composed of a mixture of different varieties. In Morocco, there are no subsidies for certified seed. So developing a new concept of genetic progress diffusion on a large scale is highly desirable. In this context, participatory plant breeding could be one option to improve the genetic value of seed used on-farm, since the time needed for a new variety to reach farmers by the official route is too long (about 12 years).

FODDER OATS IN TUNISIA

Oats (*Avena* spp.) are the most important livestock feed in Tunisia; they are grown

over a wide range of climatic conditions ranging from the humid and subhumid climates of the northeast and northwest, to the semi-arid climate of the southwestern and north-central part of the country. The areas most suited to oat growing in the humid and subhumid climatic zones are the districts of Bizerte, Beja and Jendouba, and in the semi-arid zone, the districts of Le Kef, Siliana, Zaghouan, Mennouba, Nabeul and Ariana. Oats are a component of crop rotations in rainfed farming systems. In Tunisia, farming systems are determined mainly by environmental and soil conditions and landscape. As a result, there are wide differences in cropping patterns, farm sizes and farm livestock. There are therefore various combinations of livestock and cropping (cereal and forage). In the subhumid areas, farming systems are based on a two-year rotation: cereal+legumes (broad (faba) bean, chickpea or fenugreek (*Trigonella foenum-graecum*)); cereal+cereal; or cereal+forage. However, a wheat–oat–legume rotation is common. In the semi-arid areas, farming systems are based on either cereal production or livestock (particularly sheep), with a high percentage of small farms (less than 5 ha). Traditionally, the rotation is a clean or weed fallow followed by a cereal crop (wheat or barely). Crop rotation with other cereals (wheat or barely) or legumes, such as broad bean (*Vicia faba* L.) or chickpea (*Cicer arietinum* L.), reduces the build up of pest populations in the soil and controls weeds. The inclusion of oats in a rotation as a control measure for soilborne diseases in wheat is a standard recommendation of the General Directorate of Agricultural Production, Ministry of Agriculture. Weed control is helped through cutting at the heading stage to make hay. Oats are used either as a fodder or as a cash crop.

Farmers who do not own livestock produce oat hay for sale; these are mainly large-scale cereal growers who already have the equipment for wheat production so have only to acquire simple haymaking and baling equipment to go into commercial haymaking. The commercial cereal growing areas are in the north of Tunisia, mostly in and around the valley of the Mejerda, and have a rainfall of between 500 and 800 mm. Rainfall and temperature data for a typical station in the cereal growing area are shown in Figure 5.8.

An efficient transport system ensures that the baled crop is moved by road to the weekly market places in different regions, from where it is transported to other regions in the centre and south. Oats, for hay, represent over 60 percent of the winter cultivated forage area. A large proportion of oat hay is produced in the northern, high-rainfall, districts and sold to livestock owners in the central and southern parts of the country. The areas sown to oats mixed with vetch, mainly *Vicia sativa* L., and oats alone have changed. During the past five seasons, of the 174 000 ha of oats grown, it is estimated that only 30 percent were sown as oats+vetch mixture, while 70 percent was pure oats, of which an average of 10 percent was harvested for seed (Table 5.3). Other major fodder crops grown in the country are dual-purpose barley (long-term grazing followed by harvest for grain), vetch (*Vicia sativa*), berseem (*Trifolium alexandrinum*), sulla (*Hedysarum coronarium*) and lucerne (*Medicago sativa*). For each species, a breeding programme is in progress and cultivars have been released, such as Bekra

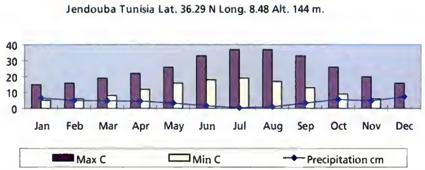

Figure 5.8
Average monthly precipitation and temperatures for Jendouba, Tunisia.

21 for sulla (Zouaghi, pers. comm.) and Mghila for vetch (Hassen, pers. comm.). Hay yields are low, averaging 3 t ha^{-1}.

Oats are sown in autumn (15 October–15 November). Generally, local markets supply oat seed, including certified seed, which accounts for less than 10 percent of local production. In dry years, most oat seed is imported. For example, in 1994 and 1995, 10 958 and 10 735 tonne of seed, respectively, of cv. Mortlock were imported from Australia. Depending on seasonal conditions and forage needs, oats are fertilized with nitrogen when grown for hay. Special establishment techniques and management regimes are followed when growing oats for grain production.

Research on oats began in Tunisia in 1913, with the establishment of the Botanical Service (later becoming INRAT). Boeuf (1914) reported oat evaluation tests to determine grain and forage potential of 29 introduced lines. The first selected oat variety was described and released by the Tunisian Botanical and Agronomic Service (Seguela and Jacquard, 1953). Until recently, there were two varieties used: Creme (*Avena byzantina* Koch.), the red local variety, which became susceptible to lodging and crown

TABLE 5.4
Evolution of area (ha) sown to oats, vetch, triticale and fenugreek

Use	Crop	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Hay	Oats+Vetch	59 490	26 775	26 899	28 252	24 991	18 842
	Oats	87 160	100 062	110 424	121 055	111 796	125 725
	Others	22 400	22 505	20 520	21 166	22 025	21 809
Silage	Oats+Vetch	17 918	15 629	15 266	13 115	11 675	12 228
	Triticale	–	–	2 280	3 057	4 806	4 581
	Others	3 574	3 245	2 135	2 843	3 320	2 452
Seed	Oats	20 751	17 719	18 751	18 442	18 951	20 268
	Vetch	2 030	1 639	1 401	1 930	1 387	1 992
	Fenugreek	3 080	2 661	2 507	3 150	2 565	3 328

Source: General Directorate of Agricultural Production, Ministry of Agriculture, 2001.

rust; and Avon (*A. sativa* L.), introduced in 1962, early maturing and susceptible to the major foliar diseases.

In 1975, an oat breeding programme started at the Cereal Genetic Laboratory of INRAT, with the screening and evaluation of hundreds of lines for forage and grain under subhumid conditions. These lines were received from Dr H. Shands of the University of Wisconsin (Maamouri *et al.*, 1988; Rondia *et al.*, 1985). Strong selection pressure was applied for foliar disease resistance and high forage and grain yield potential. Within 10 years, 11 genotypes/lines had been selected for further evaluation for foliar disease resistance, height and maturity, and for forage and grain yield potential. These lines were: Av. 3, Av. 14, Av. 72, Av. 77, Av. 81, Av. 86, Av. 88, Av. 89, Av. 90, Av. 93, and Av. 95. However, precise information on their performance was limited. Later, another programme determined the performance of a number of commercially available cultivars, mainly from Australia. Under Tunisian conditions, cultivars including Dolphin, Swan, Bulban, Winjardic, Mortlock and Potoroo were susceptible to diseases, particularly to crown rust.

In 1990, a serious crown rust epidemic caused yield losses of around 30 percent in the widely grown Australian cv. Swan (DGPA, 1990). The same phenomenon was observed in spring 1995 on cv. Mortlock.

In 1993, oat breeding was transferred to the Forage Production Laboratory and integrated into the priority forage improvement project. An agronomic evaluation confirmed previous results on these oat lines. Based on their performance over locations and years (1994 to 1996), the better genotypes were described and registered (Chakroun and Maamouri, 1998). The best genotypes were subsequently named cv. Fretissa (Av. 3), cv. El-Alia (Av. 14), cv. Meliane (Av. 77) and cv. Mejerda (Av. 89). Nevertheless, they do not have adequate adaptation for growing in all oat areas.

The short-term breeding strategy now is to select cultivars from the Quaker International Oat Nursery (QION), which is designed to breed oats for developing countries. Ninety-five pure lines of oats obtained in 1996 from QION were evaluated in a multilocation trial. After five evaluation cycles, four lines from this material were selected on the basis of high dry matter (DM) forage yield, earliness and tolerance to the major diseases. These lines have the potential to produce high forage DM and good grain yield. Only one line (Av. 9) has been presented for registration.

Recommended varieties

The oat cultivars currently recommended for the subhumid region of Tunisia are Avon, Fretissa, El-Alia, Meliane and Mejerda. These have good agronomic characteristics and some resistances to foliar diseases (Tables 5.4 and 5.5).

Seed production

Limited use of new cultivars can be attributed to the lack of good extension and the failure to establish a seed multiplication strategy. In collaboration with the National Agricultural Development Organization and the National Seed Inspection Service, the Forage Production Laboratory at INRAT is engaged in the establishment of efficient oat seed production. In 1994, multiplication of four newly released oat cultivars began with four generations of commercial multiplication:

TABLE 5.4
Plant height, maturity, straw strength, DM yield (as a percentage of cv. Avon), grain yield and 1000-grain weight of four registered oat cultivars in Tunisia

Variety	Plant height	Maturity	Straw strength	DM yield (as % of Avon)	Grain yield (t ha⁻¹)	1000-grain weight (g)	Use
Fretissa	Medium	Early	Thick	148	3.2	42	Silage
El-Alia	Very tall	Late	Thin	160	1.5	17	Hay
Meliane	Tall	Medium	Thick	159	4.1	40	Silage
Mejerda	Very tall	Late	Thin	149	2.0	30	Hay

TABLE 5.5
Disease reactions of four oat cultivars in Tunisia

Cultivar	Crown rust	Powdery mildew	BYDV
Fretissa	R	S	R
El-Alia	MR to S	S	S
Meliane	S	S	MR
Mejerda	S	S	S

KEY: R = Resistant; MR = Moderately resistant; S = Susceptible.

Pre-basic, basic and certified first and second generation seed. This work was carried out with the Office of Livestock and Pasture at Fretissa farm, yielding over a hundred tonnes of certified oat seed. Under direct supervision of the National Seed Inspection Service, government and private seed organizations are now involved in the production, processing, marketing and distribution of good quality seed. Local seed production companies produce oat seeds in collaboration with INRAT through a formal agreement.

Prospects

Oats are the major grown forage crop in Tunisia and play a key play in both productive and sustainable agricultural systems. Variety choice is one of the most important decisions that a farmer must take. Oat farmers in Tunisia often sacrifice yield when they grow cultivars relatively unadapted to their region and circumstances.

In order to improve the productivity of this forage, a three-pronged strategy is necessary. First, a national programme of oat breeding to select cultivars having good resistance to the major diseases, well adapted to the Tunisian agro-ecological conditions and with different maturities; specific emphasis must be placed on crown rust, BYDV and powdery mildew, which are the major diseases of oats in Tunisia. Second, to test, by extensive and regional variety trials, the most important forage cultivars available internationally, mainly from Spain, USA and Australia. In Tunisia, seed production depends on the amount and distribution of rain; in favourable years farmers produce over 80 percent of the required seed. In dry years, seed production is poor, necessitating imports of oat seed. In this case, Tunisian farmers will be helped to choose the more suitable oat cultivars available on the international market. The third and last component of the strategy is to give more attention to the development of improved management practices and preparation of technology transfer packages for large-scale seed multiplication.

FODDER OATS IN ALGERIA

In Algeria, oats and vetch in mixture is the most popular fodder crop. The area sown varies from year to year, but is steadily

declining. In 1986, around 364 000 ha were sown for hay or green feed, but this had fallen to only 91 000 ha in 1998. The area sown for grain to be used as feed or seeds also fell, from 137 000 ha in 1986 to 58 600 ha in 1998. The reasons for this reduction are partly due to climate, with the increasing tendency to drought and warmth during winter and spring. Oats are particularly sensitive to hot, dry weather from head emergence in winter to maturity in late spring. Despite this reduction in area, oats remain the most important animal feed, with almost 70 percent of the dried forage used in the country. This crop is usually integrated in the farmer's annual activities. However, its productivity per unit area remains low, mainly due to poor agronomic practices.

Farmers use oats in three different ways: as hay in mixture with a legume (vetch or pea); as green feed; or as grain for seed production and ruminant feed. Oats are fed as hay, silage, straw and grain, separately or with concentrate compounds. Sheep, lambs, cattle and horses are the most important livestock fed oats. No data are available about feeding oats to poultry. Oats are most often fed on the farm where they are grown, and only a little enters the marketplace. So the economies of oats and their role in livestock production need to be elucidated. Oats alone or with a legume, when conserved under good conditions, provide good quality hay with 0.7 Forage Unit per kilogram DM. However, little effort is given to management, so hay quality is poor, averaging 0.4 Forage Unit per kilogram DM (Ouknider and Jacquard, 1986). Oats are not eaten by humans in Algeria.

Mixed rainfed oats and vetch are grown in the northern region along the Mediterranean shore from Oran to Annaba. This region is characterized in normal years by areas with high precipitation receiving more than 600 mm, and another area specialized in cereal production (wheat and barley) with 350 to 500 mm (Hamrit, 1995). Sowing is normally in November and harvest for silage in April, for hay in June and for grain in July and August.

Farmers prefer to sow wheat and barley on the better land, with oats on less fertile and marginal land. Oats alone or in mixture with vetch are generally sown late, and the crops frequently remain without either fertilizer or weeding. More data about farming systems and the place of oat therein were unavailable, and information is needed on this topic. Diseases, mainly rusts, on this crop are not controlled in the subhumid and humid regions, where they have caused significant losses in some years. Limited local seed production has been another important factor affecting oat production and area extension. Because profitability in this sector, compared with other cereals, has been very low, farmers are reluctant to use tested and certified seed. Moreover, the limited number of oat cultivars available and their poor adaptation to the different agro-ecological zones, from the humid northern to the arid southern regions, militate against expansion of the crop.

Oat varieties

In Algeria, the number of oat varieties used by farmers has been very small. Besides the local landraces (Guelma 4, Rouge 31, Cowra 977, Noir 912), the predominant cultivars are Avon, from Australia and Prevision from Spain. They have performed well and are

accepted by farmers. Little is known about the Algerian oat due to lack of any programme for collecting, conserving, evaluating and exploiting the local *Avena* genetic resources.

Ongoing research

At the Institut Technique des Grandes Cultures (ITGC), several recent studies have been undertaken to improve oat productivity. The main topics include:

- Studies on mixtures: vetch+triticale and vetch+oats were the best combinations, with high DM yield (used as hay) and with good forage quality.
- Maturity synchronization of vetch and oats to identify vetch cultivars that flower at the beginning of oat heading. The results showed coincidence for vetch cvs Valor and Languedoc.
- Seed proportion in mixtures: the best proportion was 1/3 oats and 2/3 vetch.
- Oat variety evaluation: the best oat cultivars were Lorentz, Alfred, IS4160 and 4110S.

Important themes for future activities include development of new technical practices (sowing date, sowing rate); selection of new cultivars with resistance to foliar diseases; and development of dual-purpose oats (DM yield and grain production).

FODDER OATS IN THE LIBYAN ARAB JAMAHIRIYA

The Libyan Arab Jamahiriya is characterized by a harsh climate, which has been aggravated in recent years by a net reduction in rainfall. There are two main regions: the eastern region, where agriculture depends exclusively on rainfall, and the western region, which uses supplementary irrigation in addition to rainfall.

TABLE 5.6
Forage crop areas in the Libyan Arab Jamahiriya

Forage crop	Area (ha)
Berseem (*Trifolium alexandrinum*)	45 699
Oats	22 430
Other forages	16 455
Total	84 584

Source: Ouchen, 1997.

Forage crops are sown on about 85 000 ha (Table 5.6).

Oats is the second-largest forage crop in the country, as shown in Table 5.6. Cultivated alone or in mixture with a forage legume (vetch or forage pea), it can be grazed or used as hay. It seems to be the forage crop most adapted to the climatic conditions of the country.

Oat seed production varies from 700 to 20 000 kg ha^{-1}, depending on rainfall. Oat seed yield is not as high as that of wheat or barley (Table 5.7), but, economically, oats seem to be the most profitable crop, as is shown in Table 5.8.

Further work should include variety selection, with emphasis on cultivars selected from Morocco and Tunisia; collection and evaluation of local oat varieties; strengthening the information system concerning all aspects of oat development; and training and technology transfer to farmers regarding oat seed production.

CONCLUSIONS

Fodder oats are an essential component of the livestock system in the Maghreb. They are well integrated into the cropping systems and will continue to be the preferred forage in most favourable areas. Current forage production from oats is far from the potential maximum. Farmers, are still using uncertified seed and do not respect the technical norms for

TABLE 5.7

Oat seed production yields (quintal ha⁻¹) of cereals in the Libyan Arab Jamahiriya according to the rainfall

	Rainy year		Normal year		Drought year	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Wheat	2608	2313	1566	1500	1067	844
Barley	2550	2200	1814	1547	891	885
Oats	2371	1744	1573	1261	1163	688

SOURCE: Ouchen, 1997.

TABLE 5.8

Net benefit (dinar per ha) from cereal seed production in the Libyan Arab Jamahiriya

	Rainy year	Normal year	Drought year
Wheat	356.15	84.52	- 62.98
Barley	449.98	65.17	- 49.63
Oats	774.20	254.90	+ 120.10

SOURCE: Ouchen, 1997.

oat production. A large extension effort is needed to demonstrate all the existing results from oat research in the Maghreb. Towards this end, an Oat and Vetch Maghreb Network has been established, with an initial focus on varietal trials. Its main objectives are to (i) strengthen Maghrebian cooperation, and (ii) transfer results of investigations on oat and vetch.

Cereals – wheat and barley – still received most attention from policy-makers, since they are the major food crops in the region. It does not help that oat is not a mandate crop for any CGIAR centre, such as CIMMYT or ICARDA, that cooperates with the Maghreb counties. Most international cooperation now places emphasis on socio-economic and environmental aspects rather than technical or scientific aspects.

Research to date has been compartmentalized, concentrating on oat variety selection and agronomy, with minimal collaboration in animal feeding work or the overall economics of integration of oats and fodder into mixed livestock-crop production systems.

ChapterVI
Fodder oats in Pakistan

Muhammad Dost

SUMMARY

The introduction of improved cultivars of oats has changed the status of the oat crop in Pakistan in less than twenty years: from a minor crop limited to a few stations, to one of the most important cool-season fodders. Livestock, mainly stall-fed, are very important in Pakistan's agricultural economy. Crop residues and fodder form the basis of the ration, with concentrates for commercial stock. Agricultural land is limited, so increased forage availability has to be through increasing yield per unit area. Introduction of the new oat cultivars coincided with expansion of dairying and gave impetus to commercial forage growing in the irrigated tracts. The main winter fodder, berseem, which is still grown on a vast scale, yields well in autumn and in spring, but performs poorly in the coldest weeks of winter. The methodology for introducing, screening, selecting, field testing and extending are described, along with the very necessary seed bulking and distribution. Special attention is given to the great success of oats in the Northern Areas[1] at altitudes from 1000 to 2300 m, to help overwinter stock that graze alpine pastures in summer.

BACKGROUND

Pakistan has a chronic fodder shortage, with two pronounced deficit periods. The most serious deficit period is December to January, when the traditional winter fodders of berseem (the major winter fodder; *Trifolium alexandrinum*), shaftal (*Trifolium resupinatum*) and lucerne (*Medicago sativa*) are dormant. The other critical period is May to June, when the summer fodders of maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and sorghum-Sudan grass hybrids (*Sorghum vulgare* var. *sudanense*) have only just begun growth, but the winter fodders are finished. Until recently, seed of improved fodders, especially multicut oats, has not been available, so there has been a scarcity of fodder in terms of both quantity and quality.

Berseem is a case of astonishingly successful introduction and uptake by the farming community. It was introduced to Sindh from Egypt between eighty and ninety years ago, and within twenty years was the main winter forage throughout lowland Pakistan and the northern irrigated tracts of India, displacing the former winter legumes *Trifolium resupinatum* and *Melilotus indica* almost totally.

Oats (*Avena sativa* L. and *Avena byzantina* Koch) rank fifth (Dost, 1997) in terms of world production of cereals, and are widely used as a companion crop for undersowing forage legumes. Oats are mainly grown in temperate and cool subtropical environments. In Pakistan, they

1 A territory administered by Pakistan, comprising the disputed territories other than Azad Jammu and Kashmir – the old Gilgit Agency.

are an important winter fodder, in both irrigated and rainfed areas.

The green yield of local oat landraces under rainfed conditions is about 20 t ha^{-1} (Bhatti, Hussein and Mohamamd, 1992), which is insufficient to provide even maintenance for the number of livestock kept. In winter, dairies have to buy fodder in large quantities from distant, irrigated tracts. In contrast to local landraces, improved oats grow faster, can be cut earlier and provide feed during the cold period. In Balochistan, wheat was a traditional fodder, but, with the introduction of improved oats, use of wheat fodder has fallen. Farmers harvest oats at 50 percent flowering, or later to maximize yield but at the expense of quality (Dost, 1997).

The ideal fodder oat should be high in crude protein and digestibility, and low in crude fibre. Fodder yield and quality is greatly influenced by plant age, crude protein content and *in vitro* dry matter digestibility, which falls as the forage crop matures; dry matter yield increases with advancing maturity (Dost *et al.*, 1994). Appreciating the importance of oats as a promising fodder, and to palliate the winter feed problem, oat cultivars were obtained from countries thought likely to be the best sources of suitable germplasm.

FARMING SYSTEMS AND CROPPING PATTERNS

In Pakistan, most crop production is in four major farming systems, reflecting local agro-ecological zones, defined by climatic conditions, dependence on irrigation or rainfall, temperatures, soil fertility and land holding size.

Medium to high altitude

This includes the mountain and hill regions, such as the northern parts of North West Frontier Province (NWFP), the Northern Areas and parts of Balochistan. Although some areas get reasonable rainfall, Gilgit and the Northern Areas are in a rain shadow and have to rely on irrigation from snow or glacier melt. Holdings are very small, and arable areas are limited to scattered, irrigable alluvial fans. Crops are often undersown in orchards. Agriculture is purely subsistence. Livestock includes both cattle and small ruminants. Dry stock and small stock may go on transhumance. These areas are 1000 to 2300 m above the plains, with cold to extremely cold winters. At medium elevations, maize, rice, potatoes, wheat, barley and shaftal are grown; above 2000 m, seed potatoes, wheat, buckwheat, foxtail millet, barley, oats and lucerne are grown.

Medium altitude rainfed tracts

This includes the Pothowar plateau, Rawalpindi-Islamabad, Attok, Chakwal, Jhelum, Mianwali, Dera Ghazi Khan (Punjab), Bannu, Karak, Kohat, parts of Dera Ismail Khan (NWFP), and most of Balochistan. Temperatures are similar to the irrigated areas, but depend on rain. Large ruminants are important, and forage production is very seasonal; there may be some rough grazing. Major crops are mustard, wheat, barley, oats and lentils in winter; maize, sorghum, millet, guar and groundnut in summer. Maize is an important dual-purpose crop in high-rainfall regions, but is replaced by groundnut in drier areas.

Irrigated tracts of the plains

This is a vast area, and includes central and northern Punjab, parts of NWFP, Sindh

and Balochistan. The bulk of Pakistan's agriculture occurs here, with intensive commercial farming over very large areas. Large ruminants, especially dairy buffaloes, are important, and are stall-fed on crop residues and fodder. With warm temperatures and plentiful irrigation, conditions are optimal for luxuriant crop growth for ten months of the year. These areas are subtropical, with searingly hot summers. Wheat, cotton, sugar cane, maize, rice, lucerne, berseem and oats are major crops. These areas meet almost all the grain and forage requirements of urban dairies, including those in rainfed regions.

Coastal areas

These areas – south Sindh and parts of Balochistan – have subtropical conditions. Pearl millet, sorghum, maize, sugar cane, barley and oats are common. Rainfall is scattered and erratic and so irrigation is of extreme importance. The major winter forages are oats, berseem, lucerne, vetch and mustard; summer forage crops are maize, sorghum, sorghum-Sudan grass hybrid, pearl millet, cowpea and guar.

Cropping patterns

Most farmers in rainfed regions grow local landraces of traditional forages. Livestock are fed on dried maize, sorghum or millet stover, and graze wild grass. In winter, green wheat is fed. Poor feed results in poor health and production. In prolonged droughts, even productive animals are sold to get cash for domestic needs. In the rainfed tracts, forage availability is the major criterion in deciding what kind of stock to keep.

Sorghum with maize, and mustard intercropped in wheat, are the major green forages, supplemented by maize thinnings and weeds. Barley and oats are forages generally grown for sale near urban areas, mainly under tubewell irrigation. Several thousand tons of oat forage are transported to urban dairies daily in season and thousands of urban dairies rely on daily purchase of forage. Forage fetches reasonable prices in winter. In dry seasons, peri-urban farms cannot meet the forage requirements of city dairies, so forage is transported from irrigated areas hundreds of kilometres away. In rainfed areas, wheat straw and sorghum, maize or millet stover provide the bulk feed; forages and concentrates are fed to lactating animals.

Livestock rearing has evolved specialized crop management practices – e.g. intercropping of companion crops, maize thinning and fallowing of land – to help to feed animals. There are three very different fodder situations.

- In rainfed areas, agriculture is for subsistence and crops depend on rainfall. Forage requirements are partly met through forage crops and partly by grazing fallows.
- In the irrigated tracts, peri-urban forage production is commercial.
- In the high mountains, forage production and stock rearing are for subsistence and feed needs are partly met through forage from very small holdings, where irrigation is available, and partly through using alpine grazing to the maximum extent.

On the plains, there are two very different types of stock rearing: subsistence and commercial; the latter is in peri-urban "milk shed" areas or even in towns. Some farmers grow for their own stock (again subdivided into subsistence and com-

mercial), while others (who may have no livestock) grow fodder as a cash crop. Commercial forage farmers cultivate very intensively and usually grow four crops per year on the same piece of land.

Commercial dairies are mostly found around big cities such as Karachi, Hyderabad, Lahore, Sheikhupura, Gujrat, Gujranwala, Rawalpindi-Islamabad, Faisalabad, Peshawar, Charsada, Nowshera, Quetta and Mirpur AJK[2]. Feed for animals is transported by road – lorries over long distances or camel, bullock or donkey carts for forage produced locally. Some forage is transported over 300–400 km, such as from Hyderabad, Sukkar and Nawab Shah to Karachi; from Kasur, Sheikhupura, Gujranwala, Faisalabad and Renala Khurd to Mirpur (AJK) and Rawalpindi-Islamabad; and from Nowshera, Charsada, Mardan and Malakand to Peshawar. Cities in irrigated regions have forage sources quite close by, but Karachi, Islamabad-Rawalpindi and Mirpur buy feed from afar.

Buffaloes predominate in Punjab, NWFP and Sindh, as their milk is preferred and fetches a high price. In Quetta, less than half of the urban herd is buffalo, due to lack of irrigation and consequent scarcity of green and dry forage. Afghan refugees brought pure and grade Friesian cattle to Quetta (and management skills) and their excellent condition and performance has attracted local dairymen to cattle.

Rising transport costs have encouraged the making of oat hay. Data are not available, but huge quantities of oats are now regularly made into excellent hay, baled and transported over long distances. In the 1950s and 1960s, oats were grown mainly to provide hay for horses, then the main transport animal in rural and urban areas. The rapid rise in the popularity of oats over the last fifteen years is due to the introduction of high-yielding cultivars that provide several cuts, such as cvs Scott, S-81, Tibour, Cascade, Swan and PD2-LV 65. In the late 1980s, the dairy industry began to expand and more and more milk marketing outlets became available. A large number of milk processing units have been installed. The expanding urban population has provided a lucrative milk market and dairy farming is now better managed.

Forage production is an important business, especially near big cities, with a range of crops grown to maintain a year-round supply. Improved, multicut oats are very popular in urban irrigated areas, and have almost replaced poor quality wheat and rice straw as the basis of winter feed; berseem provides very high quality cool-season forage and is marketed in vast quantities, but production peaks in spring and is poor in the coldest months. Improved oats provide forage in cold weather and are replacing the forage brassicas that were formerly used in the winter gap (Suttie, 2000a).

Forage yields are low compared to their potential. Improved cultivars and technology have been slow to reach the small farms that account for the bulk of production, and seed production has lagged behind plant breeding and introduction. Recent on-farm work has indicated that yields could be raised by two to three times using available cultivars and technology. Where land and irrigation are the major limiting factors to increasing fodder production, intensification is the

[2] Azad Jammu and Kashmir.

only way to meet the country's needs for forage.

Oat introduction

Fodder oats were introduced during the early British era, but it was only in the 1970s that 400 cultivars were acquired from Australia, Canada, Europe, New Zealand and USA to form the basis of Pakistan's oat improvement programme. Further importations were made under a World Bank Hill Farming Project for Azad Kashmir in the 1980s. Some of this material still plays an important role across a wide range of ecologies. The National Agricultural Research Centre's (NARC) Fodder Research Programme also introduced material from Western countries in the mid-1980s.

The Fodder Research Institute, Sargodha, is the main institution handling the basic seed production of improved or promising forages. It has 200 ha of irrigated land for breeding, evaluating, screening, management testing, selecting and recommending forages, especially for the irrigated tracts. It has substations in Faisalabad and Bahawalpur in different eco-climates. As a result of the improved access of the farming communities to seeds of improved forage cultivars around Sargodha and Faisalabad, both cities are now major sources of fodder as a cash crop, which is hauled over great distances throughout Punjab. Forage cultivars released by the Fodder Research Institute and other stations are listed in Table 6.1.

Improved oats have now been used by farmers, usually around big cities for some 20 years; they provide assured feed in early winter if sown at the end of August or early September, to be cut in late November – early December.

Seed multiplication and extension

NARC, Islamabad, is responsible for introducing new varieties of forage crops in Pakistan and evaluates all introduced forage cultivars for forage and grain yield traits. Promising introductions are evaluated and multiplied in different agro-ecological zones (Figure 6.1). Selected cultivars are further evaluated in national uniform evaluation trials at all appropriate substations. Most substations multiply promising cultivars. NARC, Islamabad, and FRI, Sargodha, have larger areas for bulking seed, which is then sold to small-scale farmers, commercial growers, government agencies, private dairy farms, agencies and organizations interested in fodder production and development. Most seed of improved forage and cereal cultivars is produced by private companies, government centres and to a limited extent, commercial growers. The bulk is purchased for further multiplication, and the surplus sold to private dealers who market it in rural areas. Local seed dealers are the main source of oat seeds for small- and large-scale commercial farmers.

Until recently, small-scale farmers did not know the potential of forage oats and never grew them. Bridging the conceptual gap between improved cultivars and technology and the fodder growing on farmers' fields was a clear challenge. An FAO-assisted project in the early 1990s organized demonstrations and supported larger-scale multiplication of promising, well-tested forage cultivars. The outputs and findings of this successful project, which gave a great impetus to commercial oat growing, is reported by Bhatti and Khan (1996)

A Productivity Enhancement Project in 1997–98 carried out large-scale, on-

TABLE 6.1
Forage crop cultivars released by various institutes in Pakistan

Crop	Cultivar	Institute and station	Year released
Oats	Avon	FRI, Sargodha, Punjab	1983
	PD2-LV 65	FRI, Sargodha, Punjab	1983
	Sargodha-81	FRI, Sargodha, Punjab	1983
Barley	Frontier-87	CCRI, Pirsabak, NWFP	1988
	Jau-83	AARI, Faisalabad, Punjab	1985
	Jau-87	AARI, Faisalabad, Punjab	1988
Berseem	Agaiti	FRI, Sargodha, Punjab	1986
	Pachaiti	FRI, Sargodha, Punjab	1986
Maize	Akbar	MMRI, Sahiwal, Punjab	1972
	Azam	CCRI, Pirsabak, NWFP	1973
	Kisan-90	CCRI, Pirsabak, NWFP	1990
	Sultan	MMRI, Sahiwal, Punjab	1986
	Mazenta (Maize × Teosinte)	FRI, Sargodha, Punjab	1991
Millet (*Pennisetum*)	Barani bajra	RARI, Bahawalpur, Punjab	1986
	Hairy dwarf	RARI, Bahawalpur, Punjab	1986
	Composite-75	RARI, Bahawalpur, Punjab	1986
	MB-87	FRI, Sargodha, Punjab	1991
Sorghum	Jowar-86	RARI, Bahawalpur, Punjab	1986
	BR-307	RARI, Bahawalpur, Punjab	1986
	BR-319	RARI, Bahawalpur, Punjab	1986
Sorghum-Sudan grass	Hybrid Pak-sudax	FRI, Sargodha. Punjab	1986
	SSG-988	Pioneer Seed Pvt. Ltd.	1992
	Ras Bheri	Cargill Seeds Pvt. Ltd	1993

KEY TO INSTITUTES: FRI = Fodder Research Institute, Sargodha; CCRI = Cereal Crops Research Institute, Pirsabak, NWFP, which works under the Ayyub Agricultural Research Institute, Pirsabak, NWFP. AARI = Ayyub Agricultural Research Institute, Faisalabad; MMRI = Maize and Millet Research Institute, Sahiwal; RARI = Rainfed Areas Research Institute, Bahawalpur.

farm demonstrations and seed multiplication of improved oats throughout the country. Village producers were linked with private seed companies and seed dealers in all cities for sale and purchase of improved oat seed. Companies and dealers became a major means of oat seed bulking. Seed procured by dealers is now regularly traded in rural markets. Most farmers save most of their own seed from an initial supply from merchants.

Non-governmental organizations working at grassroots level in rural areas over almost 70 percent of the country have been playing a very important role in demonstrating improved forages. Interested communities indicate their needs for seed, rural support programmes arrange procurement from reputable sources, and deliver to the farmers' homes. Thus seed of improved oats have become accessible to small-scale farmers, even in remote areas. For the past several years, the NARC Fodder Programme and private seed companies have been actively involved in the seed multiplication of improved oats for the FAO Afghan Programme.

OATS AS FODDER

Forage oats are grown throughout Pakistan and are now the main source of winter and spring forage from the plains – both irrigated and rainfed – to high altitudes (1000–2300 m). Oats account for more than 35 percent of the land under

Figure 6.1
Fodder yield trial with improved oat cultivars, Pakistan

forages in Pakistan. Seed yields vary from 2.4 to 3.2 t ha^{-1} in the better environments, but less at higher altitudes (above 2300 m). In the Northern Areas, at 2000–2300 m, the highest recorded green fodder yields were in the range of 80–120 t ha^{-1}.

Oat fodder is important in the plains during autumn, winter and spring, and in the mountains in autumn, spring and early summer. Reported green fodder and dry matter yields are generally higher in parts of NWFP and Balochistan than in the lowlands and mid-hills. In the Northern Areas, oats have proved invaluable for stall-fed dairy cattle around villages and towns.

Temperate and cool subtropical conditions suit oats. A well distributed rainfall of 400 mm and an optimum temperature range of 16–32°C from September to April are sufficient to grow it as a fodder. Oats can provide green fodder after 60–70 days in an emergency to carry stock over the scarcity period, but by 90–100 days after germination, large quantities of fodder is available. Oats are mostly fed green, and any surplus is made into hay. It is highly palatable to all stock and the straw is much superior to wheat and barley straw. It is high in total digestible nutrients, digestible crude protein, fat, vitamin B_1 and minerals such as phosphorus and iron. Oat grain is particularly valuable for horses, dairy cows, poultry, young and breeding animals.

Oats in the Northern Areas

New oat cultivars introduced to the Northern Areas have proved to be valuable since they grow much earlier and more vigorously than traditional winter cereals. Green oats are cut in Gilgit

and Chilas when no other green feed is available. Higher yields (up to three times) are produced in the 1000–2300 m band compared with lower zones, possibly reflecting better agro-ecological adaptation. Many cultivars have been positively evaluated in winter up to alpine areas, around 2300 m. Feeding green oats to cows in winter increased milk yields by from 1 to 4 litres per day. Fodder oats, vetch, lucerne, shaftal and berseem seed are produced for on-farm use, barter and sale to earn extra cash.

Forage quality

Cattle can be maintained in good condition as many cultivars provide good forage if cut at flowering or soon after. Broad-leaved cultivars produce a higher forage yield, but narrow-leaved ones are preferred by horses and cattle. Although 16–19 percent of the total cropped area in Pakistan is planted to fodder, animals are generally underfed. To operate an efficient and economic livestock industry, high yielding, nutritious and multicut fodder oats are needed to feed more animals (Dost, 1997). Hussain *et al.* (1993) reported that cv. Fatua oats produced more fodder and less crude protein with advancing crop maturity. The crop should be harvested at a stage that provides an optimum compromise between forage yield and quality. Maximum green fodder and dry matter yields and crude protein contents were recorded when oats were harvested at 50 percent flowering. Hussain *et al.* (1994) also reported that the highest dry matter yields of five oat cultivars were at the 50 percent heading stage.

Dost *et al.* (1994) concluded that forage yield, dry matter yield and crude fibre increased with advancing maturity, while crude protein declined. Harvest at 50 percent flowering resulted in superior forage and dry matter yields, but inferior nutritive forage value, defined by lower crude protein and higher crude fibre contents, compared with harvesting at the vegetative stage at 70 or 85 days after sowing. Minimum forage and dry matter yields with maximum forage quality came from harvesting at the mid-vegetative stage, 70 to 85 days after sowing. Young cereal plants provide excellent quality herbage, which is highly nutritious for lactating ewes and young growing lambs.

Maturity period

Time from sowing to heading or maturity is a good indicator for the selection of dual-purpose crops. In the high rainfall areas of Punjab, the recommended dual-purpose oat, cv. S-81, was the earliest to mature after heavy defoliation. It was, however, the latest when ungrazed and grown for grain (Dost, 1994). This trait of late maturity in a dual-purpose crop was confirmed by McLeod *et al.* (1985) when cutting oats at 2 cm. Hadjichristodoulou (1983) and Yau *et al.* (1987) concluded that dual-purpose lines tended to be late heading, and time to heading or maturity appeared to be the main factor affecting yields, while tiller number, head number and plant height were less important (Yau *et al.*, 1987).

Oat research and development

NARC, Islamabad, evaluated 400 cultivars (1970s introductions) throughout Pakistan and, based on maximum forage yield, dry matter yield and maturity, selected 20 that were then further evaluated in all four provinces in the autumn (*rabi*) season under a wide variety of conditions, to

select and recommend the most suitable for different agro-ecological regions. Year-round fodder production is the most important component in local farming systems and a great deal of research is being carried out in the four provinces of Pakistan as part of a national coordinated fodder research programme. The details are presented below.

Genotype × environment interaction and screening methods

Considerable genotype × environment interaction has been noted across latitude, altitude, seasonal sequence and management regimes; this is poorly documented in Pakistan. Effectiveness of a variety testing programme is influenced by experimental design, number of locations, and the number of years used to average variety means. Information is required as to whether forage oat varieties respond differently when planted under diverse environment interactions, and, if so, how important such genotype × environment interactions might be in an oat variety evaluation and selection programme.

Dost *et al.* (1993) studied the optimum allocation of resources in varietal evaluation for thirteen oat genotypes for forage yield at four locations for four years, and suggested that, for an efficient forage oat evaluation programme, the three provinces under study should be divided into sub-areas on the basis of variation in rainfall, temperature, soil type and soil fertility in order to minimize genotype × environment interaction (Table 6.2).

Oats as a multicut crop

Compared with wheat and barley in Pakistan, oats provide multiple cuts, tiller profusely, yield more and are of higher nutritional value. Standing oats can be cut progressively, releasing land earlier than normal for follow-on crops or relay cropping. Any remaining oats can be dried as hay. This coincides with optimum soil moisture for land cultivation and sowing of the following crop, and also allows small areas or peripheral lines on terraces to be saved for seed. In many, but not all, instances, more recently bred cultivars out-yield older ones (Dost *et al.*, 1994). Although the use of oats as a multicut crop is common in Pakistan, relatively limited research data are available to aid the farmer in the selection of the best forage harvest schedule for the dual utilization of oats to attain high forage yield, seed yield and good forage quality.

Bhatti, Hussain and Mohammad (1992) evaluated 13 oat cultivars under a two-cut

TABLE 6.2
Expected variance of a variety mean (Vx) for various assumed numbers of replicates and locations per test

No. of replicates	Over 2 years No. of locations						Over 4 years No. of locations					
	2	4	6	8	10	12	2	4	6	8	10	12
2	2.25	1.29	0.97	0.81	0.71	0.65	1.18	0.67	0.50	0.42	0.37	0.34
3	2.22	1.27	0.96	0.80	0.70	0.64	1.16	0.67	0.50	0.42	0.37	0.34
4	2.20	1.26	0.96	0.79	0.70	0.64	1.16	0.66	0.50	0.42	0.37	0.33
5	2.19	1.26	0.95	0.79	0.70	0.64	1.15	0.66	0.50	0.42	0.36	0.33
6	2.18	1.26	0.95	0.79	0.70	0.64	1.15	0.66	0.50	0.41	0.36	0.33

Source: Dost *et al.*, 1993

system at Islamabad during 1985–86 and 1986–87 and found that the cultivars PD2-LV 65 and S-81 produced 28.05 percent and 26.24 percent more green forage and 26.30 percent and 21.93 percent more dry matter yield, respectively, in two cuttings compared with the control. Thus oat cultivars PD2-LV 65 and S-81 were found suitable for multicut systems under both irrigated and rainfed conditions.

Oats as an intercrop or companion crop

In order to obtain early and good yields on small holdings in winter, compatible fodder crops may be sown in mixture to produce higher fodder yields and quality per unit area per season (Table 6.3). Low growing leguminous fodders, such as berseem and vetch, can be mixed with oats, ryegrass, brassicas, etc. (Figure 6.2). Oat+vetch (Figure 6.3) and barley+vetch combinations produced on average 110 and 70 t ha^{-1} of green material, compared with 100 and 56 t ha^{-1} pure oat and barley stands, respectively, in the 1400 to 2000 m altitude band (Table 6.3).

A deep-rooted crop like lucerne can be mixed with shallow rooted ones like oats, rye, barley or a brassica; the annual is usually sown between the rows of perennial fodder. This technology has

TABLE 6.3

Green and dry matter yields (t ha^{-1}) of oats, barley and vetch at two sites in 1994–1997

Crop	Gilgit		Chilas	
	Green	Dry	Green	Dry
Oats	100	21	105	23
Oats+vetch	110	24	102	22
Barley	56	12	59	14
Barley+vetch	70	16	76	18

Source: Dost, 1997.

TABLE 6.4

Green and dry matter yield (t ha^{-1}) of oat cultivars at the National Agricultural Research Centre, Islamabad, during 1985–87 (average of two years)

Cultivar or line	Green matter yield				Dry matter yield			
	1st cut	2nd cut	Total	Relative yield(1)	1st cut	2nd cut	Total	Relative yield(1)
DN-8	27.15^{ab}	45.99^{c}	73.14	+ 7.22	5.185	17.936	23.121	+ 6.31
Algerian (control)	25.46^{ab}	42.75^{cd}	68.21	0.0	4.862	16.886	21.848	0.0
W. No. 11	23.30^{b}	42.28^{cd}	65.68	- 3.85	3.984	16.892	20.876	- 4.01
Avon	23.76^{b}	45.21^{cd}	68.97	+ 1.11	3.944	17.632	21.576	- 0.79
Fulgrain	27.47^{ab}	44.75^{cd}	72.22	+ 5.88	5.246	17.452	22.698	+ 4.37
Sargodha-81	29.32^{a}	56.78^{a}	86.10	+ 26.24	5.893	21.576	27.469	+ 26.30
Golden rein	29.16^{a}	43.67^{cd}	72.83	+ 6.78	5.103	15.502	20.605	- 5.25
Swan	26.85^{ab}	49.84^{b}	76.69	+ 12.43	5.235	17.792	23.024	+ 5.86
PD2-LV 65	29.32^{a}	58.02^{a}	87.34	+ 28.05	5.805	20.713	26.518	+ 21.93
Kent	28.40^{a}	45.37^{cd}	73.77	+ 8.15	4.629	16.424	21.053	- 3.19
Java Lahori	27.77^{ab}	41.51^{d}	69.28	+ 1.56	4.804	15.151	19.955	- 8.24
A. fatua	26.85^{ab}	45.37^{cd}	72.22	+ 5.88	4.994	16.877	21.871	+ 0.56
Eagle No. 1	25.00^{ab}	44.14^{cd}	69.14	+ 1.36	4.550	16.552	21.102	- 2.97

Notes: Means followed by the same letters do not differ significantly at the 5% level of probability. (1) Percentage more (+) or less (-) than control.

Source: Bhatti *et al.*, 1992.

Figure 6.2
A mixture of oats, lucerne and brassica

Figure 6.3
Oat and vetch hay mixture in Gilgit, Pakistan

TABLE 6.5
Green and dry matter yields (t ha⁻¹) of legumes and oats at Gilgit in 1993/94

Treatments	Green yield	Dry matter yield
Lucerne	70	18
Lucerne+oats	115	30
Berseem	80	17
Berseem+oats	135	30
Red clover	63	16
Red clover+oats	94	26

Source: Dost, 1997.

been demonstrated to the farmers in the Northern Areas. There are many advantages of mixed sowing over pure: more than one crop per season per unit area; weed control is easier; yields are higher than pure-sown crops; and fodder is of better quality. Oats were intercropped in winter-active lucerne and red clover in rows 30 cm apart at several sites. The mixtures of lucerne+oats, red clover+oats and berseem+oats produced greater green and dry matter yields compared with the sole crops of either legume. The results are presented in Table 6.5.

Oat+berseem mixtures provided earlier and greater fodder yields, and increased milk production by as much as 20 litres per animal per month on average, compared with traditional practices. At the same time, the demand for purchased concentrates was reduced by 20 kg $month^{-1}$ per animal, and milk production was extended by an extra two months.

Multiple cropping or mixed sowing techniques were tried. The details are presented in Table 6.6. Non-winter-dormant lucernes (Sundar being the main cultivar) have been very successful. They may suffer some frost damage at high altitudes, but grow throughout the year and yield more than twice as much as the landraces in double crop areas below 2000 m. They also provided maximum green feed in the critical December–January period.

Little information was available in Pakistan on forage quality in crops harvested at various stages of maturity, so studies were carried out to determine the ideal stage to obtain a compromise between maximum forage yield and reasonably good forage quality. Hussain *et al.* (1998) evaluated oats, barley and wheat for forage yield and quality at nine growth stages at Islamabad during 1990–2. Oats harvested at head emergence stage and barley and wheat at full flowering produced maximum green yields. In all three crops, the highest dry matter yield was recorded at early dough stage. The maximum crude protein content was recorded at four-leaf stage repeatedly, whereas minimum protein contents were recorded in the early dough stage. Oats, barley and

TABLE 6.6
Effect of mixed sowing on green and dry matter yields (t ha^{-1}) of lucerne, red clover and oats at three sites in 1996/97

Treatment	Sultandabad		Rahimabad		Saling	
	Green	Dry	Green	Dry	Green	Dry
Lucerne cv. Sundar	110	30	105	26	68	20
Red clover	60	16	62	18	50	13
Oats	100	32	95	30	80	26
Lucerne+oats	140	39	136	37	102	30
Red clover+lucerne	115	32	108	26	70	22
Red clover+oats	90	26	93	28	75	23

TABLE 6.7

Green and dry matter yield and crude protein contents of oats, barley and wheat under various cutting regimes

Cutting stage(1)	Green fodder yield (t ha^{-1})				Dry matter yield (t ha^{-1})				Crude Protein (%)			
	Oats	Barley	Wheat	Mean	Oats	Barley	Wheat	Mean	Oats	Barley	Wheat	Mean
CS 1	37.66	33.15	21.73	30.84	5.81	4.80	3.93	4.85	14.93	13.47	12.56	13.65
CS 2	40.43	35.74	26.26	24.15	7.13	5.75	4.78	5.89	14.07	12.78	11.97	12.34
CS 3	56.45	44.77	24.49	41.90	10.68	7.49	4.67	7.61	12.65	11.70	11.53	11.36
CS 4	67.16	51.30	28.80	49.09	12.41	9.21	6.52	9.39	10.80	9.85	10.21	10.28
CS 5	69.44	48.45	31.78	49.89	12.15	8.05	7.41	9.21	8.75	8.42	8.15	8.44
CS 6	64.60	56.39	30.66	50.55	11.43	10.26	7.08	9.59	8.10	7.72	7.50	7.77
CS 7	68.21	58.42	40.51	55.71	13.35	11.17	9.83	11.44	7.63	7.54	7.32	7.50
CS 8	64.27	53.93	33.95	50.72	13.99	13.40	10.83	12.74	7.50	7.02	6.96	7.16
CS 9	51.21	42.52	33.72	42.52	17.17	14.67	12.23	14.69	7.15	6.85	6.75	6.92
Mean									10.17	9.22	9.48	

KEY: (1) CS 1 = Repeated cutting at 4-leaf stage; CS 2 = Repeated cutting at tillering; CS 3 = Repeated cutting at jointing; CS 4 = Repeated cutting at boot stage; CS 5 = Harvesting once at head emergence; CS 6 = Harvesting once at 50% flowering; CS 7 = Harvesting once at 100% flowering; CS 8 = Harvesting once at early milk stage; CS 9 = Harvesting once at early dough stage.
SOURCE: Hussain *et al.*, 1998.

TABLE 6.8

Green and dry matter yields and crude protein of oats and barley as influenced by different cutting regimes

Cutting stage(1)	Green yield (t ha^{-1})			Dry matter yield (t ha^{-1})			Crude protein (%)(2)		
	Oats	Barley	Mean	Oats	Barley	Mean	Oats	Barley	Mean
CS 1	46.02	39.63	42.82	7.40	5.58	6.49	14.93	13.47	14.20
CS 2	51.39	42.04	46.71	9.23	6.91	8.07	14.07	12.78	13.43
CS 3	69.35	48.68	59.02	12.63	8.26	10.45	12.65	11.70	12.18
CS 4	79.45	55.19	67.32	13.96	9.37	11.66	10.80	9.85	10.33
CS 5	72.69	51.16	61.92	12.66	7.39	10.02	8.75	8.42	8.59
CS 6	70.98	54.95	62.96	11.48	10.00	10.74	8.10	7.72	7.91
CS 7	77.78	63.10	70.44	14.18	11.12	12.65	7.63	7.54	7.59
CS 8	73.26	58.22	65.74	14.09	11.70	12.90	7.50	7.02	7.26
CS 9	51.97	45.72	48.84	15.54	13.75	14.64	7.15	6.85	7.00
LSD(P=0.05)	10.47	7.40	–	2.94	2.08	–	–	–	–

NOTES: (1) CS1= Repeated cutting at 4-leaf stage; CS2 = Tillering; CS3 = Jointing; CS4 = Booting stage; CS5 = Harvest once at ear emergence; CS6 = 50% flowering; CS7 = 100% flowering; CS8 = Early milk stage; CS9 = Early dough stage; LSD = Least Significant Difference; P = Probability. (2) Data for one year.
SOURCE: Hussain *et al.*, 1995.

wheat harvested at boot stage provided a good compromise among green fodder yield, dry matter yield and forage quality. At this stage, a sufficient quantity of fodder with moderate forage quality was obtained (Table 6.7). More recent work on oats has been reported by Hussain *et al.* (in press).

Hussain *et al.* (1995) report on trials in 1990 and 1991 that evaluated yield and quality of fodder at different harvesting stages of oats and barley (Table 6.8). Oats at the boot stage and barley at full flowering produced maximum forage yield (79.45 and 63.10 t ha^{-1}, respectively). In oat and barley, the highest dry matter yields (15.54 and 13.75 t ha^{-1}, respectively) were recorded at early dough stage. In both crops, crude protein content decreased with advancing maturity. The

maximum crude protein content (14.93 and 14.37 percent in oats and barley, respectively) was observed when the crops were harvested repeatedly at the four-leaf stage, whereas the minimum was at the early dough stage in both crops. Oats and barley harvested at booting proved better for reasonable forage yield (67.32 t ha^{-1}), dry matter yield (11.66 t ha^{-1}) and forage quality (crude protein 10.33 percent). At this stage, a sufficient quantity of forage yield with adequate quality was obtained in both crops (Table 6.8).

Dual-purpose oats

Seed production is a major problem for many forage crops, as most of them are harvested and fed to livestock well before seed formation, unless intentionally kept for seed. Development and cultivation of dual-purpose forage varieties could be one means to ensure seed availability. Dost *et al.* (1994) evaluated oat cv. S-81 under different maturity and harvesting treatments during 1991–92 at Islamabad (Table 6.9). Forage yield, dry matter yield and crude fibre increased, while seed yield and crude protein declined when harvesting the crop with advancing maturity. Maximum forage and dry matter yields with considerably inferior quality forage (as defined by lower crude protein and higher crude fibre values) were observed at 50 percent flowering stage. Minimum forage and dry matter yields with superior quality forage were recorded at 70 and 85 days after sowing. This research also indicated that it is possible to obtain satisfactory forage yield, forage quality and grain yield from oats that have already been cut once for forage at 115 days after sowing.

Fertilization of winter forages

Different doses of nitrogenous and phosphatic fertilizer produced substantially higher yields at five locations in Pakistan (indicated in Table 6.10) than using no fertilizer or farmyard manure (FYM) alone, especially on seriously depleted soils that had been monocropped for many years with cereals. Maximum forage yields were obtained through application of 150-75 N-P kg ha^{-1} at most sites, followed by 150-25 N-P kg ha^{-1} (Table 6.10). However, increased use of fertilizer could

TABLE 6.9

Average plant height (PH), tillers per plant (TL), leaves per tiller (LV), green fodder yield (GY), dry matter yield (DY), seed yield (SY), crude protein content (CP) and crude fibre (CF) contents of oats cv. S-81 in Islamabad, 1991–92

Treatment(1)	PH	TL	LV	GY	DY	SY	CP	CF
CT 1	63.63^{d}	6.18^{c}	4.89^{c}	13.59^{d}	2.07^{d}	0.85^{b}	12.29^{a}	22.32^{d}
CT 2	83.70^{c}	6.80^{ab}	5.89^{b}	16.92^{d}	2.57^{d}	0.54^{c}	12.25^{a}	22.94^{c}
CT 3	90.06^{bc}	6.89^{ab}	6.26^{ab}	23.46^{c}	4.08^{c}	0.48	8.68^{b}	24.50^{b}
CT 4	94.74^{b}	7.07^{a}	6.59^{a}	33.33^{b}	6.60^{b}	0.46	8.46	25.58^{a}
CT 5	134.78^{a}	6.46^{bc}	6.56^{a}	54.99^{a}	12.99^{a}	–	7.94	25.60^{a}
CT 6	–	–	–	–	–	1.34^{a}	–	–
LSD (P = 0.01)	10.70	0.54	0.63	4.73	1.24	0.24	0.34	0.36

NOTES: Means followed by the same letters do not differ significantly at 1% probability level. (1) CT1 = Cut for fodder 70 days after sowing and then for seed; CT2 = Cut for fodder 85 days after sowing and then for seed; CT3 = Cut for fodder 100 days after sowing and then for seed; CT4 = Cut for fodder 115 days after sowing and then for seed; CT5 = Cut at 50% flowering for fodder only; CT6 = No fodder cut but left for seed only; LSD = Least Significant Difference; P = Probability.
SOURCE: Dost *et al.*, 1994.

TABLE 6.10

Green yield ($t\ ha^{-1}$) of oat cv. Scott under different fertilizer doses and sites in 1999–2000

Fertilizer N-P kg ha-1	Green fodder yield				
	Islamabad	Tandojam	Tarnab	Sariab	Faisalabad
100-25	74.69	59.56	30.78	46.00	96.29
50-50	61.11	52.16	28.01	42.33	79.32
50-25	56.79	57.40	25.23	40.33	70.37
50-75	61.11	55.24	28.94	47.33	101.23
150-25	80.86	74.99	29.40	45.33	98.45
150-75	87.04	74.09	30.78	56.66	112.04
100-50	74.69	62.34	31.95	50.00	99.38
00-00	37.65	44.13	27.78	32.00	52.16

TABLE 6.11

Green-fodder yield ($t\ ha^{-1}$) and gross income ($Rs\ ha^{-1}$) from five oat cultivars with five treatment regimes, Islamabad, Pakistan, 1987–89

	Cv. Fatua		Cv. S-81		Cv. PD2-LV 65		Cv. Avon		Cv. Swan		Mean	
Treatment[1]	Green fodder yield	Gross income	Green fodder yield	Gross income	Green fodder yield	Gross income	Green fodder yield	Gross income	Green fodder yield	Gross income	Green fodder yield	Gross income
T1	13.61	6 600	13.59	6 410	13.79	6 480	10.66	5 190	10.30	4 890	12.39	5 910
T2	17.02	6 980	16.92	6 870	20.16	8 220	14.35	5 8.90	16.93	7 000	17.08	6 990
T3	22.32	7 600	23.46	7 910	2948	9 810	22.22	7 330	26.75	9 120	24.85	8 350
T4	31.38	8 640	33.38	9 050	37.76	10 300	30.35	8 170	36.52	9 980	33.88	9 240
T5	39.51	10 120	54.99	13 800	58.90	14 750	42.23	10 680	54.58	13 720	50.24	12 610
Mean	20.64	6 660	23.73	7 340	26.68	8 260	19.97	6 210	24.18	7 450		

Interaction matrix

LSD (P=0.01)	Green fodder yield	Gross income
Varieties (V)	1.96	0.72
Cutting stages (CS)	1.75	0.62
V × CS interaction	4.81	1.77

NOTES: (1) T1 = Cut for fodder 70 days after sowing and then harvested for seed at maturity; T2 = Cut for fodder 85 days after sowing and then harvested for seed at maturity; T3 = Cut for fodder 100 days after sowing and then harvested for seed at maturity; T4 = Cut for fodder 115 days after sowing and then harvested for seed at maturity; T5 = Cut for fodder at 50 percent flowering stage for fodder. LSD = Least Significant Difference. P = Probability.

not be justified in many instances for economic and environmental reasons.

Effect of cutting or grazing on forage and grain yield

As little information was available on the economics of oat production in Pakistan, a study was undertaken on the economic aspects of oats harvested for fodder and fodder+seed at different harvesting intervals. Generally, farmers cut oats either for fodder or grain, but there is good scope to obtain both fodder and seed from the same crop.

Hussain *et al.* (1994) evaluated five cultivars of oats for fodder yield, seed yield and gross income at different harvesting intervals during 1987-89 at NARC, Islamabad (Table 6.11). Cvs PD2-LV 65, S-81 and Swan produced maximum forage yield (58.6, 55.0 and 54.6 $t\ ha^{-1}$) and gross income (Rs 14 750, 13 800 and 13 720), respectively, when harvested only for fodder at 50 percent flowering

TABLE 6.12

Seed yield (t ha⁻¹), gross income (Rs ha⁻¹) from seed and gross income (Rs ha⁻¹) from fodder+seed (F+S) from five oat cultivars with different treatments, Islamabad, 1987–89

	Cv. Fatua		Cv. S-81		Cv. PD2-LV 65		Cv. Avon		Cv. Swan		Mean		
Treatment[1]	Seed yield	Gross income from F+S	Seed yield	Gross income from F+S	Seed yield	Gross income from F+S	Seed yield	Gross income from F+S	Seed yield	Gross income from F+S	Seed yield	Gross income from seed	Gross income from F+S
T1	1.18	13 340	0.85	11 300	1.86	16 950	1.71	14 900	2.04	16 440	1.53	8 670	14 580
T2	1.43	15 020	0.54	9 950	1.77	18 100	1.52	14 470	2.07	18 600	1.46	8 230	15 230
T3	1.47	15 970	0.48	10 650	1.48	18 010	1.24	14 290	1.73	18 980	1.28	8 220	15 580
T4	1.16	15 360	0.46	11 670	1.41	18 380	1.01	13 870	1.28	17 450	1.06	6 100	15 340
T5	–	10 120	–	13 800	–	14 750	–	10 680	–	13 720	–	–	12 610
T6	1.37	7 880	1.26	7 210	2.19	12 380	1.32	7 660	1.82	11 150	1.59	9 060	9 060
Mean	1.10	12 950	0.60	10 760	1.45	16 430	1.13	12 650	1.49	15 880	–	–	–

Interaction matrix

LSD(P=0.01)	Seed yield	Gross income	Gross income from F + S
Cultivars(Cv)	0.206	1.18	1.31
Cutting stages(CS)	0.216	1.25	1.31
Cv x CS interaction	0.500	2.89	3.21

NOTES: (1) T1 = Cut for fodder 70 days after sowing and then harvested for seed at maturity; T2 = Cut for fodder 85 days after sowing and then harvested for seed at maturity; T3 = Cut for fodder 100 days after sowing and then harvested for seed at maturity; T4 = Cut for fodder 115 days after sowing and then harvested for seed at maturity; T5 = Cut for fodder at 50 percent flowering stage for fodder. LSD = Least Significant Difference. P = Probability.
SOURCE: Hussain *et al.*, 1994.

stage. The highest seed yield (2.19 t ha⁻¹) and gross income (Rs 12 380 ha⁻¹) were obtained from PD2-LV 65 harvested only for seed (see Table 6.12). Cv. Swan cut for fodder after 70 and 85 days of sowing and then left for seed produced, respectively, 2.04 and 2.07 t ha⁻¹ seed yield and Rs 11 520 and 11 590 ha⁻¹ gross income. The maximum cash incomes from fodder+seed were obtained from cv. Swan harvested for fodder after 85 and 100 days (Rs 18 600 and 18 980 ha⁻¹) and cv. PD2-LV 65 harvested 115 days after sowing (Rs 18 380 ha⁻¹). It was therefore concluded that it was more economic to cut oats for fodder at 85–115 days after sowing and then leave the regrowth for seed at maturity (Table 6.12).

Forage and hay yield

Evaluation and selection of oat cultivars with high fodder yield, good fodder quality and disease resistance is an important factor in meeting the fodder requirements of livestock. Trials evaluating and selecting multicut, and high-fodder-yield cultivars were carried out on farmers' fields in the Northern Areas during 1996-97. The results are presented in Table 6.13.

Hussain *et al.* (1993) evaluated 15 oat cultivars for forage yield, dry matter yield, crude protein and crude fibre contents at NARC, Islamabad, in 1985–86 (Table 6.14). Cultivar No. 725 produced taller plants, more tillers per plant, more leaves per unit leaf area, the highest forage yield, dry matter, and superior forage quality.

National uniform oat forage yield trials

Twenty promising cultivars were evaluated across a range of altitudes and ecologies during the 1980 and 1990s, from

TABLE 6.13

Dry matter yields (t ha^{-1}) of five oat cultivars and barley in 1996-97 at four sites in the Northern Areas, Pakistan

Cultivar	Gilgit	Chilas	Ghizer	Skardu
5-81	24	27	21	19
Scott	20	21	18	17
Cascade	18	19	16	14
Swan	16	17	14	13
PD2-LV 65	13	15	12	10
Average oats	18.2	19.8	16.2	14.6
Barley	11	9	7	6

Source: Dost, 1997.

TABLE 6.14

Green fodder yield, dry matter yield, crude protein contents crude fibre contents of different oat cultivars

Cultivar	Green yield (t ha^{-1})	Dry matter (t ha^{-1})	Crude protein (% of DM)	Crude fibre (% of DM)
5-81	75.06^{abcd}	8.98^{cd}	10.94^{def}	22.85^{e}
PD2-LV 65	82.83^{a}	12.08^{a}	10.06^{ghi}	23.21^{cd}
Avon	68.67^{cde}	9.26^{cd}	9.65^{i}	22.48^{f}
PD2-LV 65 × Fulgrain	72.84^{bcde}	11.01^{abc}	11.06^{cd}	23.14^{d}
Avon × Early Miller	64.82^{e}	8.40^{d}	10.40^{efgh}	22.85^{e}
No. 707	67.44^{de}	9.67^{cd}	10.09^{ghi}	22.59^{f}
No. 616	66.98^{de}	9.77^{cd}	10.99^{de}	23.29^{bc}
No. 656	70.97^{cde}	9.53^{cd}	12.44^{a}	23.33^{abc}
No. 632	71.98^{cde}	9.44^{cd}	10.57^{defg}	22.79^{e}
No. 725	81.32^{ab}	11.84^{ab}	11.66^{bc}	22.32^{g}
No. 677	77.02^{abc}	10.83^{abc}	10.09^{ghi}	23.37^{ab}
No. 668	71.76^{cde}	10.36^{abcd}	9.80^{hi}	22.31^{g}
No. 681	71.45^{cde}	9.41^{cd}	12.24^{ab}	23.42^{a}
55-1	71.30^{cde}	9.83^{bcd}	10.21^{ghi}	22.57^{f}
5-141	71.14^{cde}	10.68^{abc}	10.33^{fgh}	22.81^{e}
LSD (P = 0.01)	8.55	2.05	0.62	0.13

Notes: LSD = Least Significant Difference. P = Probability. Means followed by the same letters do not differ significantly at 1% probability level. DM = dry matter.

Source: Hussain *et al.*, 1993.

sea level to above 2 000 m through a series of on-farm, farmer-managed and research station trials, plots and socio-economic surveys. Representative examples of data generated from trials in dairy pockets are given below (data obtained from the NARC report on the *National Uniform Fodder Yield Trials 1989-2000*). The performance of the cultivars is given in Tables 6.15 to 6.18.

The chemical fertilizer treatment for all the trials was 40-60-0 kg NPK ha^{-1}. There were large differences in the performance of cultivars at all sites, suggesting significant differences in agro-ecological adaptation, highlighting the importance of National Uniform Yield Trials to evaluate newly introduced material. All trials included standard control cultivars (Tables 6.15 to 6.18). Due to genotype × environment interaction, it was not possible to recommend a single cultivar across all locations. The National Uniform Yield Trial is a continuous on-farm evaluation

TABLE 6.15
Green fodder yield (t ha^{-1}) of oat cultivars at five locations across Pakistan

	Islamabad	Tarnab	Sariab	Tandojam	Faisalabad
Coolabah	42.56	29.19	47.30	20.18	88.26
Murray	36.94	27.78	51.50	22.22	89.50
Nile	33.51	30.09	45.32	17.22	90.44
Avon	40.41	27.32	46.35	22.58	94.44
Marloo	34.65	31.48	46.45	20.46	96.91
Hay	34.24	25.93	54.60	18.88	89.81
Wallaroo	31.22	33.33	44.29	23.51	79.01
PD2-LV 65 (control)	35.56	35.18	76.22	20.46	79.19

TABLE 6.16
Average green forage yield (t ha^{-1}) of oats at various locations in 1998- 99

Cultivar	Islamabad	Tarnab	Faisalabad	Sariab	Tandojam
Wallaroo	74.13	97.6	57.40	17.68	30.81
Avon	76.91	103.2	57.86	13.88	28.07
Jasper	90.84	122.6	82.86	30.09	24.40
Valley	84.95	111.9	64.80	28.24	26.54
Marloo	68.57	105.9	74.06	12.96	31.42
No. 646	84.32	132.7	82.86	18.51	29.90
Reil	91.86	122.1	56.01	20.83	32.95
Coolabah	90.94	120.3	66.19	14.81	21.96
Nile	80.62	108.7	60.18	17.12	28.07
Ozark	85.12	111.5	66.19	12.96	22.57
Murray	72.90	44.8	57.85	12.96	26.85
Foot Hill	80.51	88.3	60.63	17.59	38.44
No. 97081	91.50	125.8	77.30	21.29	30.21
Saia	88.12	101.3	56.47	24.07	20.44
Scott	80.60	101.8	68.05	21.30	31.73
Steel	81.33	99.0	72.68	23.12	19.66
Hay	88.13	116.6	68.51	27.31	21.66
Hakae	75.60	100.8	62.02	18.51	25.32
Hakae	78.90	110.5	70.36	19.90	33.56
PD2-LV 65	75.96	120.3	81.74	22.22	32.03

programme, and each year new introductions are included in these trials. In this way, promising cultivars are evaluated for their suitability for diverse agro-ecological conditions throughout Pakistan.

Date of sowing

Supply of fodder mainly depends on the time of sowing. Most farmers try to sow forage crops as early as possible to ensure early availability for livestock. In underdeveloped countries where fodder is very scarce, the time of fodder availability during deficit or lean periods is more important than the total quantity of fodder available. The recommended sowing season for forage oats in the plains of Pakistan is from October 15 to November 15. However, variations in sowing dates reflect many factors: the particular needs of the farmers for their livestock; size and composition of herd; size of land holding; time of expected rainfall; availability of fallow land; and

TABLE 6. 17
Average green forage yield (t ha^{-1}) of oats cultivars at various locations during 1999-2000

Cultivar	Islamabad	Sargodha	Tarnab,	NWFP A U	Tandojam
Saia	37.04	66.36	36.43	98.00	39.81
No. 646	38.89	69.45	34.77	103.00	41.66
Valley	33.33	61.11	36.34	100.00	41.66
Nile	38.42	69.45	52.99	110.00	46.29
Steel	34.26	73.46	00.00	98.00	46.29
Foot Hill	38.42	70.68	62.83	109.00	50.92
Jasper	38.89	71.61	59.61	97.00	46.29
Marloo	35.18	52.78	42.04	94.00	50.92
Murray	36.11	66.05	39.74	98.00	46.29
Hakae	42.13	54.01	49.68	93.00	60.18
No. 663	60.18	78.40	46.27	91.00	48.14
Sargodha 99	52.77	63.00	43.05	104.00	49.07
Winjardie	36.57	67.90	77.87	75.00	51.85
Superlate	47.22	68.83	49.68	105.00	49.99
Local Sargodha	49.09	68.21	57.96	101.00	46.29
Local Sheikhupura	45.83	71.00	51.33	80.00	41.66
PD2-LV 65	48.61	62.00	79.48	86.00	44.44

TABLE 6.18
Green fodder yield (t ha^{-1}) of oat cultivars at five locations in Pakistan during 1999

	Islamabad	Tandojam	Tarnab	Faisalabad	Sariab
Swan	71.77	39.62	20.18	43.00	43.00
Superlate	88.42	37.77	22.70	47.00	47.00
Jasper	80.65	37.77	17.03	42.33	42.33
OA330-60	95.46	35.92	19.62	48.67	48.67
Scott	96.19	38.88	24.44	54.33	54.33
Cascade	93.24	32.22	23.51	51.33	51.33
Tibor	89.91	38.70	22.59	41.00	41.00
PD2-LV 65	85.09	37.96	24.40	48 33	48.33

irrigation water supply. In order to assess a suitable sowing date for maximizing forage yields and optimizing time of forage availability, sowing date trials on high fodder yielding oat cv. Scott were conducted at research institutes throughout the country under various agro-ecological environments. The results obtained are presented in Figure 6.4.

At Islamabad and Tandojam, the 20 October sowing, and the 20 November sowing at Sariab, provided maximum forage in December–January, the fodder deficit period. September-sown crops provided acceptable yields in November at all sites; time of fodder availability is directly correlated with sowing time.

Seed production

The introduction of improved cultivars is one of the quickest methods of improving and enhancing yields of all crops. Soon after identification of potential new cultivars, seed bulking, seed distribution and ensuring seed availability to the common farmer are important steps in successful extension. Therefore, all the effort involved in introducing, evaluating

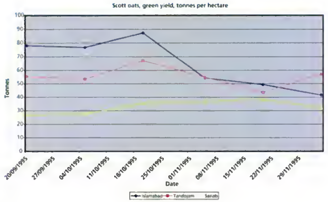

Figure 6.4
Green yields (t ha^{-1}) of oat cv. Scott.

Figure 6.5
Development of seed production of improved oat cultivars in Pakistan, over two decades

and selecting improved forages is in vain if there is insufficient seed produced and made available to the farmer.

In Pakistan, most seed of improved forage and grain cultivars is produced by private companies, government centres and, to a limited extent, by commercial growers. NARC, Islamabad, produces annually almost enough to sow 500 ha. The seed thus bulked is sold to farmers,

commercial growers, government and private dairy farms and other agencies and organizations interested in improved oat fodder production and development. In recent years, seed of improved oats has also been sold to the FAO Afghan Programme for multiplication and distribution there. The development of improved oat cultivar seed produced and sold by NARC, Islamabad, and others is presented in Figure 6.5, which clearly shows a steady increase in the production of improved seed. However the demand for improved seed is much greater than the quantities marketed. All the seed of improved fodder oats is used for further increase and subsequent sale to fodder growers of the area.

CONCLUSIONS

Livestock have always been a very important part of the agricultural system in Pakistan, but lack of good quality fodder has been an ongoing major constraint on production. Pakistan faces a situation where there is insufficient fodder, in terms of both quantity and quality. High quality fodder is necessary if better returns are to be obtained from improved breeds. Technical development to improve forage production and supplies could be of immense benefit to the health and prosperity of the people. Oats have proved to be an outstanding winter forage throughout Pakistan, particularly for the peri-urban dairies supplying the big cities, and in the high altitude temperate northern regions. Growing oats ensures production of maximum quantities of early, nutritious forage in the deficit periods in winter. It is safe to claim that oats have brought a winter forage green revolution in Pakistan.

Over the past two decades, improved oat cultivars have had a significant impact in improving quality and availability of livestock feed, and, hence, on the lives of people living in resource-poor areas of Pakistan. Forage from oats has helped significantly in mitigating livestock starvation and in improving nutrition, both of animals and of the human population. The recent significant impact of new oat cultivars on the availability of livestock feed and therefore on farmer incomes in resource-poor areas of Pakistan has stimulated the belief that even more can and should be done, both to make existing cultivars more widely available through extensive bulking and to introduce new, better-adapted oat cultivars and other improved fodder crop varieties, thus supporting resource-poor regions through continuous on-farm evaluation with the help and cooperation of the national forage research programme, extension services, private seed companies and NGOs.

Chapter VII
Fodder oats in the Himalayas

7.1 EXPERIENCES WITH OATS (*AVENA SATIVA*) AT TEMPERATE AND HIGH ELEVATIONS IN BHUTAN

Tsering Gyeltshen

SUMMARY

Traditionally, after harvesting high altitude paddy, farmers grow wheat to feed their livestock during the dry winter. Oats (*Avena sativa*) were introduced to Bhutan in the early 1970s, but adoption by farmers was limited, except in Dopshari. Recently, oats have become popular in the rice system, after trials and field demonstrations. During 2001–02, a total of 550 farmers brought 59 ha under fodder oats in Thimphu and Paro districts. Oats are more palatable than wheat and yield more than double the amount of green fodder, and are a multicut crop. Oats have the potential to be an important winter fodder in Bhutan, also allowing important land use intensification. Farmers still grow substantial amounts of wheat to provide flour for religious ceremonies and brewing local alcoholic beverages. The demand for oat seed is also increasing among yak herders, who grow oats in summer to make hay. The Bhutan extension programme has released one oat cultivar, cv. Fodder Oat Bhutan. A few other lines and exotic cultivars have been tested and are under observation in farmers' fields. Promising cultivars are Stampede and Naked.

Introduction

Oats are a recent crop in Bhutan; the variety commonly used was probably introduced in the 1970s from Japan or India. According to a progressive farmer (who has been an oats promoter in Dopshari for more than 20 years), oats were introduced following a flood in Paro valley in 1969. There was nothing left for the livestock to graze and when he approached the late Dasho Nishoka, who was the Colombo Plan Expert there, he was given oat seed. From that small package, the farmer produced more seed, but oats remained confined to his farm for quite some time. Slowly neighbours showed interest and began to grow oats. In the 1970s, many oat cultivars were introduced and tested for grain, but farmers did not take up oats for grain (RNR RC, 2002). The cultivar currently in use (cv. Fodder Oat Bhutan) originated from the early introduction to Paro. Until a few years ago, oats were only popular with the few farmers of Dopshari. Some farmers are reluctant to grow oats because they resemble wild oats (*Avena fatua*), a major weed in winter cereals.

All farmers at high altitude grow winter cereals (wheat and barley) to feed livestock during lean periods. These cereals are sown after the high altitude rice harvest, when paddy fields lie fallow for five to six months. Fodder is mainly cut and stall-fed. Yak herders grow wheat and barley in summer in yak night pens, and this is made into hay.

Research on oats

On-farm tests in 1996 compared oats with the traditional fodder, local wheat. The trial was sown in the first week of November at an altitude of 2 200 m. Surface irrigation was provided at intervals of three weeks. Urea (20 kg ha^{-1}) was applied at sowing and again after first harvest. Both broadcast and line-sown oats gave three cuts and yielded 1 772 kg ha^{-1} and 1 990 kg ha^{-1} of dry matter (DM), respectively; broadcast wheat gave two cuts and 1 227 kg ha^{-1} DM. Oats were also tested under relay seeding of forage species in a rice system at Mebari, Chukha (1 820 m), during 1997–98. They were broadcast into the rice crop a few weeks before rice harvest, with no tillage, and the results were very poor: the green yield recorded was 2.7 t ha^{-1} (Roder *et al.*, 2001).

At Soe Yaksa (4 000 m) in 2001 (May to September), a replicated trial was carried out in winter yak pens to evaluate cereal fodders. Wheat was the lowest yielder; oat cvs Stampede and Naked had much higher yields than cv. Fodder Oat Bhutan. The fresh yields are shown in Table 7.1.

Before harvest, herders were asked to assess what they would select as a hay crop. Their preferences are shown in Table 7.2.

A similar study was undertaken in the Research Centre's adopted village at Khasadrapchu in Thimphu. It was sown on 20 November 2001, after the rice harvest. A field day was conducted subsequently, involving all 21 farmers from the adopted village. The group was taken to farmer's oat fields and research plots. Crop cuts were demonstrated and differences in fodder production between farmer-managed and researcher-managed plots were presented to the group (see Table 7.3). Farmers were also asked to assess the selection of preferred forages. The scores given by the farmers were exactly the same as the scores given by the yak herders.

The differences in yield are mainly attributed to sowing date, frequency of irrigation and nitrogen application.

In 2003, 22 cultivars were introduced with support from the Temperate Asia Fodder and Pasture Working Group. These were tested at four sites: Yusipang, Paro, Khasadrapchu and Dala (Table 7.4). At Khasadrapchu and Drala, the trial was established in a rice-based system; the seed was sown after rice harvest. At Yusipang and Paro (Khangku), the trial was on dry land in summer. The trials were laid out as randomized blocks with cv. Fodder Oat Bhutan as control. The cultivars tested (along with wheat and rye) were AC Juniper, AC Morgan, AC Mustang Canadian, Caravelle, Cascade, Fodder Oat Bhutan, Foothill, Hebei Province No. 3, Inner Mongolia No. 1, Jasper, Murphy,

TABLE 7.1
Green yields from cereals at Soe Yaksa

Fodder	Green yield (t ha^{-1})
Wheat	14.92
Triticale 2	19.00
Oats cv. Fodder Oat Bhutan	26.25
Rye	26.67
Triticale 1	26.83
Triticale cv. Double Take	32.83
Oats cv. Stampede	40.33
Oats cv. Naked	43.91

TABLE 7.2
Herders' forage preference for hay

Rank	Fodder
1	Oats cv. Stampede
2	Oats cv. Naked
3	Oats cv. Fodder Oat Bhutan, and triticale cv. Double take

TABLE 7.3
Difference in oat fodder production between farmer- and researcher-managed plots

Village	Oat yield		Remarks
	Height (cm)	Fresh green yield (kg ha⁻¹)	
Khasadrapchu[(2)]	19.57	2 068	Sown 16 Feb. 2002. Irrigated twice, and urea top-dressed once. Crop at early booting stage.
Khasadrapchu[(2)]	41.3	7 132	Sown 12 Dec. 2001. Irrigated 3 times and urea top-dressed once. Crop at flowering stage.
Rama - 1[(2)]	26.6	8 333	Sown during 9th Bhutanese month. Irrigated twice. Crop at flowering stage. No urea applied, only FYM.
Rama - 2[(2)]	41.5	12 000	Management same as Rama - 1, except urea top-dressed once. Crop at flowering stage.
Khasadrapchu[(1)]	74.66	20 000	Sown 20 Nov. 2001. Irrigated 4 times. Urea top-dressed once.

NOTES: (1) Researcher-managed trials. (2) Farmer-managed trials. Cv. Fodder Oat Bhutan was used for all trials.

TABLE 7.4
Sowing dates and site details

Site	Date of sowing	Land type	Altitude (m.a.s.l.)
Khasadrapchu	19 November 2002	Wetland	2 300
Drala	3 December 2002	Wetland after rice	1 200
Paro (Khangkhu)	7 June 2003	Dry land	2 200
Yusipang	24 July 2003	Dry land	2 600

NZ 0034, NZ 1001 NZ 9217604, NZ Stampede, PD2-LV 65, TaikoWaldern, rye S-2000 and wheat (cv. Bajoka).

At Yupisang, the trial was damaged by frost before seed could be properly set. At the other sites, Fodder Oat Bhutan and Stampede gave similar yields and were well ahead of the introductions. Further testing (Figure 7.1) will continue and it may be important to identify oat cultivars that are suitable for summer cultivation and to identify cultivars resistant to rust and lodging. It further confirms the performance of oat cultivar Stampede, which has now been released for extension.

Extension

Under the Feed and Fodder Development Programme, farmers are given perennial pasture seed, fodder tree seedlings and technical guidance on enrichment of crop residues, particularly paddy straw. Land is the greatest limitation for pasture development: farmers give priority to food crops, which is understandable. The livestock research programme has looked for alternatives, such as growing fodders under trees in orchards, or fodders that can be grown in the fallow period. Originally, oats were not eligible for free inputs supplied by the Ministry of Agriculture, but now that oats are identified as an important winter fodder in the rice system, oat seed is distributed free to farmers.

Depending on the altitude, oats can be grown in summer or winter.

(i) **Summer-grown fodder above 2 600–4 000 m.** Sown in April–May and made into hay in October for feeding yak in winter. Only small plots are planted by the yak community in Soe Yaksa in Paro district, using the winter night yak-pens.

S G REYNOLDS

Figure 7.1
Oat seed multiplication (cv. Stampede) for on-farm trials, RNR Research Centre, Bhutan

(ii) **Winter-grown fodder below 2 600 m.** Sown in November–December after rice harvest. At present, this mainly occurs in the districts of Paro, Thimphu and Trongsa. Fodder harvest is March to early May on a cut-and-carry system.

Uptake of oats use by farmers

About 80 percent of farmers in Dopshari in Paro grow oats on at least 1–2 langdos (10 langdos = 1 hectare), whereas in the rest of the blocks the adoption rate is low to almost nil (RNR RC Yuispang, 1998–2000). During 1999–2000, RC Yusipang distributed 150 kg of oat and 100 kg of rye (*Secale cereale*) seed each to Paro and Thimphu farmers for extension-led on-farm farmer-designed and farmer-managed trials. A total of 51 farmers participated. One hundred and five dairy farmers attended field days. Those growing oats reported milk increases of 1–2 bottles by feeding oats. From the subsequent year, the demand from farmers in both districts for oat seed rose; demand is higher from the semi-commercial milk production areas.

The total of oat seed supplied to farmers through the District Livestock Extension Programme in Thimphu and Paro for the last two years is presented in Table 7.5.

Oat seed production

Progressive farmers produce oat (cv. Forage Oat Bhutan) seed in Dopshari village in Paro, on rice fields in the off season, and have been selling it for quite some time to both government farms and private entrepreneurs. In 2001, three farmers sold a total of 5 582 kg at the rate of Nu[1] 20 per kilogram.

[1] National currency unit, the ngultrum, on par with Indian Rupee. At Nu 45 = US$ 1 at the time of reporting.

TABLE 7.5
Oat seed supplied to farmers through the extension programme

Dzongkhag[1]	Seed supplied (kg)	Remarks
Paro	3 500	370 farmers participated; 43.2 ha under oats.
Thimphu	2 715	180 farmers participated;16 ha under oats.

NOTE: (1) Administrative District.

Sustainability

In Dopshari village in Paro, farmers have been managing oats for over 20 years. Oat seed can easily be produced in the rice-based system, but it may be necessary to supply oat seed to villages where it is a new crop. What the farmers then need to do is retain one oat terrace for seed for their own use. However, seed production at around 4 000 m is a problem, and to make cereal growing sustainable at such elevations it is crucial to carry out seed production trials.

Oats are becoming a very popular fodder after rice in Thimphu and Paro. Traditional fodders, such as wheat, are declining due to poor yields and low palatability compared with oats. Substantial areas of wheat are grown for flour and brewing. Demand for oat seed from yak herders has also increased recently.

Constraints to growing oats

At high altitudes, oats are grown in yak night pens, which are poorly fenced due to a lack of materials. At present, juniper shingles are used, which is desirable from neither the ecological nor the solidity points of view. It is important to work with farmers to find alternatives, such as *logmashing* (a native shrub), which is not browsed by yaks, and can be used as live fences. At lower elevations, some farmers have a problem with irrigation.

Scope for introduction of cultivars

Oat cultivars cv. Stampede and cv. Naked have proven superior, at experimental sites, to the currently recommended cv. Fodder Oat Bhutan. Dost (1995) reported 20 t ha^{-1} of green fodder in Gilgit, Pakistan. Further exchange of oat cultivars among the Temperate Asia Pasture and Fodder Working Group member countries would be highly beneficial. Initially, only cv. Fodder Oat Bhutan was used in extension work, but, since 2003, both cv. Stampede and cv. Naked have been included. However if cv. Naked is planted during summer, it has rust problems. As a winter or early spring fodder, it is excellent under Bhutanese conditions.

Conclusions

Fodder scarcity is severe from January through to April. Production is at its lowest during these months and in the case of yaks, milk production is low to nil. Yak herders also report high mortality due to fodder scarcity. It is therefore very important that research addresses solving fodder shortages through introduction of promising fodders so that the herders are not at the losing end.

7.2 FODDER OATS IN THE INDIAN HIMALAYA

Bimal Misri

SUMMARY

Although oats have been grown as forage on the Indian plains for a long time, their introduction to smallholder farming in the Himalayan areas really started with the establishment of a research programme in the late 1970s. Acceptance has varied between regions, and it is in the territory of Jammu and Kashmir that oats have found an important place in the farming system; the climate makes growing of winter cereals for grain unreliable but oat fodder can be grown, rotated with summer crops. Removal of seed subsidies only slowed down the expansion of oat area in Kashmir for one season; thereafter farmers and traders developed sources outside government stations. The testing and development of cultivars adapted to Kashmir is described.

Background

The exact time and place of the introduction of oats as a crop to India cannot be ascertained with certainty but there are references to oat cultivation in Ain-I-Akbari written by Abul Fazal, the court historian of Mughal king Akbar, in 1590. Large-scale oat growing started in the early nineteenth century, when the British established remount depots for the Indian Army. Oats have developed as an important winter forage in the irrigated plains of northern India, but extension of oat growing in the Himalaya is comparatively recent. Oats were first introduced in the Jammu and Kashmir State by the then King, Maharaja Hari Singh (1925–1947) on his stud farms, with seed imported from Europe. During this period, oat growing was confined to the King's farms; local farmers did not use oats. Its introduction in general in the Himalayan region started in earnest in the late 1970s, with the the establishment of an Agrostology wing of Jammu and Kashmir Department of Agriculture, Himachal Pradesh Agricultural University at Palampur and G. B. Pant Agricultural University at Pantnagar, and organized research on oats in the Himalayan region also started.

These activities were strengthened by extensive research on production technology and varietal development of oats at the Indian Grassland and Fodder Research Institute (IGFRI) and Indian agricultural universities in the plains. In these areas, berseem (Egyptian clover; *Trifolium alexandrinum*) is very popular but can only be grown under irrigation. To find an alternative forage for rainfed areas, research on oats began and is continuing. A number of productive and nutritious oat cultivars have been released in India. The release of a cultivar is preceded by multilocation trials throughout the country under the aegis of the All India Co-ordinated Research Project on Forage Crops. Some testing centres are Himalayan sites, like Palampur (Figure 7.2), Srinagar and Almora, to identify cultivars suitable for Himalayan regions.

In spite of extensive research and extension, availability of excellent cultivars and

Figure 7.2
Oat variety trials at the Palampur Regional Research Centre of the Indian Grassland and Fodder Research Institute (IGFRI)

easy cultivation, oat has not become very popular in temperate Himalayan states like Himachal Pradesh and Uttaranchal. Only in Jammu and Kashmir have oats become widely popular and significantly improved the economic conditions of farmers, particularly small-scale and marginal farmers.

Introduction and acceptability of oats

The entire agricultural scenario in the Himalaya is typified by conflicts, paradoxes and inherent natural resource limitations. Land, the basic resource, is the greatest limitation. Continuous land fragmentation has led to an alarming proportion of small holdings. The status of land holdings in the Indian Himalaya is presented in Table 7.6. The situation is worst in the state of Himachal Pradesh, where 40 percent of farmers own only 0.65 ha or less. At the same time, all small-scale farmers rear animals to complement their earnings, but do not

TABLE 7.6
Size distribution of land holdings (as percentage of total number and total area) in the Indian Himalayas

Holding size (ha)	Northeastern Himalaya		Western Himalaya		All India	
	No.	Area	No.	Area	No.	Area
<2	78.4	35.0	87.6	52.6	78.3	32.3
2–4	14.6	24.0	9.3	25.9	13.3	23.1
4–10	5.5	19.0	2.8	15.7	7.3	27.3
>10	1.5	22.2	0.3	5.8	1.1	17.5

have enough land to produce fodder for their sustenance. The farmers' bias to growing food crops on their smallholding is understandable.

Three temperate Himalayan Indian States represent different altitudinal and latitudinal situations, and thus are different climatic entitics. The Himachal and Uttaranchal Himalaya represent the true temperate climate above 2 400 m altitude, where arable agriculture holds no promise; up to this altitude the days are sunny and temperatures are adequate for farming during winter. Rice–wheat, rice–maize and rice–potatoes are typical crop rotations, and farmers do not easily deviate from their own sequence. Consequently, the area under forage crops has not risen above 1 percent of cultivated land in the area over the last 30 years. As far as Kashmir is concerned, true temperate conditions start in the valley basins (average altitude 1 500 m). Severe winters, absolute lack of sunlight for more than two winter months and uncertainty of winter rains compel the farmers to avoid uncertain labour- and resource-intensive food crops. They have found the best answer in oats – an easy crop that can provide some output from land that otherwise would remain fallow in winter.

Oats are also becoming a popular crop in Himachal Pradesh and Uttaranchal States. As a result of extensive extension, the farmers have adopted oat cultivation. The area under oats is gradually increasing, as is evident from Table 7.7.

The sale of oat seed at Palampur is representative and the situation is similar at other places. In only one year, an additional 1 270 kg seed was sold, implying an additional area of 12.7 ha brought under oats, assuming a seed rate of 100 kg ha^{-1}. In addition, the local Agricultural University sells about 3 000 kg of oat seed annually.

TABLE 7.7
Oat seed sales (kg) in Palampur during 2000–2001 and 2001– 2002

Agency	2000–2001	2001–2002
Walia Seed Store	380	400
Jain Seed Store	300	500
Deputy Director, Agriculture Dept.	10 000	11 050

Oat cultivation in Kashmir – a success story

After its establishment, the Agrostology wing of the Jammu and Kashmir Government Agriculture Department offered free oat seed and fertilizer to farmers in 1976. In spite of extensive extension, the total uptake of the seed was only 200 kg. The efforts to popularize oats, however, continued unabated. The major players were the Agriculture Department, Animal Husbandry Department and IGFRI Regional Research Centre. The local agricultural university later joined these agencies.

About 80 percent of the cultivated fields in Kashmir formerly remained barren in winter because of the cold conditions. Farmers would switch to alternative professions in winter; and the making of Kashmiri handicrafts was a major winter occupation of farmers. Large-scale demonstrations of oat cultivation were laid out throughout the valley. These showed farmers that it is an easy crop, demanding almost no aftercare, once sown. Looking at very high demand for the seed, the Agriculture Department priced the seed after subsidizing it. The sale figures for oat seed during the period 1996/97 – 2001/02 are given in Table 7.8. The subsidy continued until 1997–98.

TABLE 7.8
Oat seed sale figures in Kashmir, 1996/97–2001/02

Year	Quantity (tonne)
1996–1997	118.31
1997–1998	140.0
1998–1999	32.13
1999–2000	77.52
2000–2001	15.65
2001–2002	62.25

Source: Director, Agriculture Department, Srinagar (Kashmir).

TABLE 7.9
Increase in area (ha) under oats in Kashmir Valley, 1996/97–2001/02

Season	Area under oats
1996–1997	12 507
1997–1998	15 320
1998–1999	14 000
1999–2000	15 600
2000–2001	17 000
2001–2002	18 000

Source: Director, Agriculture Department, Srinagar (Kashmir).

During 1998–99, the government withdrew the subsidy and started selling seeds at cost. This had a significant impact on the sale of seed, which was considerably reduced.

However, farmers started saving their own seed and sales by the Agriculture Department fell considerably. During the 1999–2000 season, the Department sold only 77.52 t of oat seed, despite an increase in area under oats. During the past five years the area under oats has risen from 12 507 ha to 18 000 ha. After the withdrawal of the subsidy, sales of seed fell, but the area under oats kept on registering a progressive increase, as shown in Table 7.9. During the past five years the area under oats fell only once, in 1998–99, when the subsidy for seeds was withdrawn.

Cultivation of oats on an area of 18 000 ha after only 26 years can be described as a real success story, and the credit for it, besides the research and development agencies, goes to this easy to cultivate and profitable crop.

Research on oats in the Himalaya

The initial evaluation and introduction of oats started in Kashmir valley during the early 1980s. Misri, Choubey and Gupta (1984) evaluated five cultivars developed by IGFRI at Srinagar, with cv. Kent used as a control. The results obtained are presented in Table 7.10.

Consequent upon the good performance of JHO 810, a trial using this line was laid out at three sites in the valley. In this trial, JHO 810 again was the best performer. The yield data obtained at three locations are given in Table 7.11.

This line was submitted to the state varietal evaluation committee for poten-

TABLE 7.10
Performance of oat cultivars for different forage attributes under a single-cut regime in Kashmir valley

Line or cultivar	Plant height (cm)	Tillers per metre of row	Leaf : stem ratio	Forage yield (t ha^{-1})	
				Green	Dry
JHO 801	91	120	0.491	11.80	2.89
JHO 802	79	102	0.701	9.13	2.54
JHO 810	87	145	0.421	28.73	6.99
JHO 815	84	99	0.549	18.93	4.91
JHO 819	99	107	0.519	13.66	2.77
Kent	102	108	0.615	192.30	47.60

TABLE 7.11
Green forage yield performance (t ha-1) of oat selections and cultivars in the Kashmir valley (1985–86)

Line or cultivar	Manasbal	Asham	Kashmir Univ.	Average
JHO 801	15.4	19.8	10.8	15.6
JHO 802	22.6	21.2	19.5	17.3
JHO 810	29.6	26.2	22.3	28.6
JHO 815	16.9	25.3	17.9	20.9
JHO 819	20.4	18.9	17.2	19.0
cv. Kent (Control)	15.8	14.9	12.2	17.8

tial release in the Kashmir valley and, after approval, was named Bundel Sheet Jai-1.

Besides IGFRI, Sher-I-Kashmir University of Agricultural Sciences and Technology, Srinagar, Himachal Pradesh Agricultural University, Palampur, and G.B. Pant Agricultural University, Ranichauri, are prominent institutions in the area, and actively involved in research programmes on varietal development, production technology and extension of forage oats.

7.3 FODDER OATS IN NEPAL[2]

Dinesh Pariyar

SUMMARY

Inadequate feed and poor nutrition during the dry winter months (December to April) are serious constraints to livestock development in Nepal. Oats had been grown in the lowlands by big landowners for over a century, but were introduced to smallholders only in the 1970s. The introduction of multicut cultivars has greatly increased the usefulness and popularity of the crop, and its cultivation is promoted. Oats are mainly grown below 1 600 m, but can grow up to much higher altitudes. With the introduction of multicut cultivars and new management technologies, the yield of fodder oats has gone up from 15–20 t ha^{-1} to 50–93 t ha^{-1}. Introduction, variety testing and on-farm technology are described. The introduction and testing programme is being greatly increased by an FAO-assisted project, and cultivars are being sought to extend the altitude range (including *Avena nuda*), as well as to improve yields and disease resistance. Details of the positive impact of oats on milk yields and farmers' income are given. Oat seed is a source of income in many areas; oats can produce 2 t ha^{-1} seed after taking one cut for fodder. The total area under oats has reached 2 172 ha, with 43 440 households growing them.

Introduction

The exact year of the introduction of oats (*Avena sativa* L.), called *jai* locally, is not documented, although Pande (1997) stated that they were introduced after the Second World War. However, during a survey in Sarlahi and Rautahat districts in 1992, farmers indicated that the big landlords of the Terai, who kept elephants as a sign of prosperity, grew oats more than 100 years ago; it is believed that they brought seed from India. Although there are native oat cultivars in parts of the Terai and in high-altitude rain-shadow areas, such as Mustang, little identification or evaluation work has been done on them. Fodder oats are principally used for dairy stock; small quantities are fed to goats, poultry and bullocks.

Nepal is a land-locked country of 147 000 km^2. Of the total land area, 27.5 percent is cropland (20.7 percent of the land is cultivated, 6.8 percent is "non-cultivated inclusions" (NCI), 11.8 percent grassland, 37.4 percent forest (with more than 10 percent tree cover), 4.8 percent shrubland, and 18.5 percent is other land, covered by ice or rocks, and urban areas. See Table 7.12).

The human population is 24 000 000 and the number of livestock is estimated at 7 020 000 cattle (including yak and hybrids), 3 520 000 buffaloes, 850 000 sheep and 6 320 000 goats. About 8 680 000 livestock units [a livestock unit is equivalent to a female adult buffalo of 300 kg liveweight] are reared on 14 700 000 ha, a density of 0.59 livestock

[2] This chapter is based on a paper (Pariyar, 2002) presented at the Fifth Meeting of the Temperate Asia Pasture and Fodder Working Group, Thimpu, Bhutan, and updated to reflect recent developments.

TABLE 7.12
Land use in Nepal, 1985–86 ('000 ha)

Region	Cultivated	NCI	Grassland	Forest land	Shrubland	Other land	Total
High hills	252	149	1 393	1 794	243	2 479	6 310
Mid hills	1 223	667	278	1 811	404	59	4 442
Terai	1 577	182	74	1 913	59	191	3 996
Total	3 052	998	1 745	5 518	706	2 729	14 748

NOTE: NCI = non-cultivated inclusions.
SOURCE: HMGN/ADB/FINNIDA, 1988.

TABLE 7.13
Feed Balance Sheet (TDN) for ruminants ('000 t)

	High hills	Mid hills	Terai	Country
Requirement for				
Buffaloes	313	1 760	515	2 588
Cattle	686	2 698	2 349	5 733
Goats	164	636	311	1 111
Sheep	76	82	29	187
Total [1]	1 239	5 176	3 204	9619
Available TDN from:				
Grazing land	208	72	31	311
Crop by-products	107	981	1 783	2 870
Forest	404	753	674	1 831
Shrubland	88	308	27	423
Non-cultivated inclusion	104	466	127	697
Total [2]	911	2 580	2 642	6 133
Balance [2] – [1]	-328	-2 596	-562	-3 486
(as percentage of requirement)	(-26.5)	(-50.2)	(-17.54)	(-36.24)

KEY: TDN = total digestible nutrients.
SOURCES: CBS, 1993; DFAMS, 1992; HMGN/ADB/FINNIDA, 1988; Pariyar, 1993.

units per hectare, which may be among the highest national stocking rates in the world (Pariyar, 1993).

Livestock is very important, both nationally and to the individual farming family, but productivity is constrained by lack of fodder. The estimated annual total fodder production in Nepal is 6 100 000 t total digestible nutrients (TDN), only 64 percent of livestock needs. The malnutrition is not, of course, evenly spread; commercial dairy stock are generally reasonably fed, while many rural cattle may be starved and stunted.

Fodder is collected from all land use systems, the major sources being crop residues, forest, grazing, shrubland and NCI. Fodder from cropland contributes 47 percent of the total available TDN. Fodder from forests contributes 30 percent; shrubland produces 7 percent; grassland produce 5 percent; and NCI contribute 11 percent of the available TDN (Table 7.13).

The great demand for food, fodder and firewood imposed by increasing human and animal populations causes continuous deforestation, overgrazing and intensive cultivation of steep slopes, and has led to severe soil erosion and environmental degradation. The average area of arable land farmed by a family has dropped

from over a hectare in the 1960s to less than 0.25 ha today. Many (almost half) rural households have less than 0.18 ha from which they can barely find half of their staple food. Impoverished families are increasingly dependent on the government as well as on communal forests and grazing land (FAO, 1992; Pariyar, 1992; HLFFDP, 1996, 1996–2001).

Role of livestock and production systems

Nepal, because of its great altitude range, has a wide range of agro-ecological zones; these may be grouped roughly according to the main physiographic regions, which define the temperature regimes, and are thereafter subdivided according to local conditions of rainfall, aspect, etc. Livestock are kept from the plains of the Terai to the rain-shadow areas of the Himalaya, and in all regions there is a strong integration of crops with livestock, forestry and marketing.

High hills (above 2 500 m)

In the high hills, people are influenced by Tibetan culture: Thakalis, Sherpas and Bhotias live in separate mono-ethnic settlements. Climate varies from warm temperate to alpine. Livestock production is based primarily on crops and grazing. Rainfed and irrigated, annual and perennial crops are grown. Plant growth is limited by low temperatures and a short growing season. Barley, buckwheat and potato are the major crops. Crop production is less efficient due to the longer time required for crops to mature.

Grazing management includes the seasonal movement of ruminants to use natural vegetation. Herds are made up of yaks, chauries (yak-cattle crosses), cattle, sheep, goats and horses, reared in semi-pastoral or transhumant systems. Livestock move in an annual cycle according to their specific requirements and the grazing available at different altitudes. Yaks occupy a high altitude ecological niche (3 000–5 000 m), chauries move between 1 500 and 4 000 m, and cattle move between 2 000 and 3 000 m. Sheep, goats and horses are more adaptable as to altitude and move between 1 200 and 4 000 m. Vegetation at high altitudes is only accessible in summer (July-September); herds move to lower areas in winter (December-March); yaks are seldom taken below 2 500 m.

Livestock provide milk and fibre and dried manure, which is a major fuel for cooking. Crossbred males (*dzopas*) are used for transport and meat for local use. Goats and sheep supply meat and fibre. The use of mules, sheep and goats for trading and transport of basic inputs (grain, salt, building materials, etc.) is an important source of income.

Mid-hills (500–2 500 m)

In the mid-hills, people are influenced by the predominant Hindu culture; Brahman, Chhetri, Newars, Magars, Tamang, Gurung, etc., live in multi-ethnic settlements. Livestock, although an integral part of agriculture, is secondary to crop growing. Climate varies from subtropical to warm-temperate, and the major cereals are paddy rice, wheat, maize and millets (especially *Eleusine coracana*).

Cattle, buffaloes and goats are the main grazing livestock; stock rearing is sedentary and the animals make daily grazing forays from their villages, returning in the evening. Forages include grazing in the forest, on cultivated land after harvest, and on fallows; residues from paddy,

maize, millet, wheat, mustard, soybean and vegetables are fed; grass is gathered from terraces and forests; and tree fodder gathered from farmer-owned and forest trees.

Local cattle graze; only lactating buffaloes and improved cattle, i.e. Jersey and Holstein crossbreds, are stall-fed, with the associated labour required. Female calves are reared as herd replacements but males are either reared for draught oxen or neglected. The disposal of surplus cattle, both male calves and cull females at the end of their reproductive life, is a problem because of religious beliefs inhibiting their sale for slaughter and use for meat.

There is potential to increase the total feed production from cultivated land by growing winter fodders such as oats, oat+vetch, and oat+pea mixtures. Concentrates include home-produced rice bran and maize flour, with barley and oats used in Surkhet, Illam, Sindhupalchok, Kavre, etc. Common salt is provided as a supplement. Compound feeds are rarely bought, unless justified by access to an urban milk market. Cattle and buffaloes provide milk, manure and draught. Sheep and goats are used for meat and fibre. Cultivation of land and transport usually rely on animal power.

Terai (<500 m)

The Terai is also characterized by multi-ethnic settlements predominantly influenced by Hindu culture. Cattle and buffaloes are kept for milk, manure and draught. Oxen are used for transport and cultivation. Although chemical fertilizers have become increasingly important in intensive cropping systems, manure is still the main source of nutrient replenishment and soil fertility maintenance. In many areas, where massive deforestation has reduced the supply of firewood, dung has become an important fuel.

Cattle, buffaloes and goats are the main grazing livestock. Stock rearing is sedentary; compared with the mid-hill region, there is less grazing land and forest, so more crop residues are fed and the amount of stall-feeding relative to grazing is greater. Although there is a similar feed shortage in winter and before the onset of the monsoon, productive and draught livestock are well looked after, while others are simply kept on rough grazing.

Feed sources in the Terai include grazing on roadsides, uncultivated land, forest (near the Siwalik), on cultivated land after harvest, and on fallow land, and crop residues (paddy, wheat, maize, millet, cotton, sugar cane tops, lentil, etc.). Growing fodder oats, berseem and oat+vetch mixtures have become popular in dairy pocket areas. Home-produced rice bran, wheat bran, maize, gur (evaporated sugar cane juice), broken pigeon pea, plus salt, are the major feed ingredients, fed alone or with rice and wheat straw. Cattle generally graze, but are also fed crop residues and forage crops. Lactating buffaloes and improved cattle receive supplementary concentrates.

Female calves are kept as herd replacements; male calves are either reared as draught oxen, or neglected, slaughtered, or sold to buyers from India. Buffaloes, which are also used for ploughing in the Terai, are rarely used for draught in the mid-hills.

Importance of oats

Inadequate feed during the dry winter (December-April) is one of the biggest constraints to livestock development.

Although Rajbhandary and Shah (1981) reported that "livestock get the most green matter from June to September and the quality of forage available during this period could be regarded as more or less adequate", it is different in winter, when rice straw, maize stover and other fibrous crop by-products are important foods (Gatenby, Neopane and Chemjong, 1989), because crop residues are of very poor quality. In the hills and the Terai, animals are semi-starved for seven months. Malnutrition over two-thirds of the year drastically reduces their condition and adversely affects production. There has always been a need to find a source of green forage for winter (Kshatri, Chejong and Rai, 1993).

Oat adaptation

Oats and vetch (*Vicia villosa* var. *dasycarpa*) can be grown on all soils, unless they are alkaline or waterlogged, in all regions where wheat and barley are grown. They grow at low altitudes, where winter wheat and barley are cultivated, so they are summer crops at higher altitudes. Oats are quick growing, palatable, succulent, nutritious, acceptable to all categories of livestock and can be fed in many forms, such as green forage, silage, hay, straw and grain, including during the lean period (December to April). Vetch can fix atmospheric nitrogen in the soil. The Food and Agriculture Organization (FAO, 1984, as quoted by Kshatri, Chejong and Rai, 1993) reported that vetch could fix up to 110 kg N ha^{-1} and could also be grown in the winter as a forage.

Although two oat cultivars (Kent and Swan) had been used on Livestock Development Farms since the 1970s, oats were first introduced to Nepalese farmers on a relatively large scale during the First and Second Livestock Development Projects, from 1980 to 1994. This introduction of oats for farmers' use had two major objectives:

- to alleviate inadequate feed and poor animal nutrition during the dry winter, and
- to reduce the cost of production of animal products, mainly milk.

Up to the mid-1980s, cvs Swan and Kent were grown over most of the country, and then 22 cultivars were brought from New Zealand. The Pasture and Fodder Division started adaptability testing with multilocation trials, particularly in Pakhribas, Lumle, Tarahara, Janakpur, Ranjitpur, Nepalganj and Khumaltar. In the 1990s, cv. Canadian was included at testing sites and two cultivars from Pakistan, Swan (PAK) and PDLV G-5 (PAK) were put into the programme. Again in the 1990s, cultivars, including Bundel 851, Bundel 810, JHO 822 and JHO 810, were received from India.

Oats are grown by farmers up to about 2 000 m, although the economic fodder production level is about 1 600 m on irrigated land. Oat growing is concentrated mainly on irrigated land in the Terai (Figure 7.3) and Low Hills and on rainfed land in the Low and Mid-hills. Oats are mainly used as green feed in winter and early spring, but some hay is made, mainly at higher elevations, and some high-altitude farmers use surplus seed as concentrate feed.

Cultivar evaluation

Detailed on-station testing is done at Khumaltar (NARC Headquarters, Kathmandu; 1 320 m) and a range of sta-

Figure 7.3
Cutting oats for fodder in the Terai zone

tions (Figures 7.4, 7.5 and 7.6). Agronomic characteristics, green matter yield and seed yield are studied to enable the Department of Livestock Services to prepare suitable, productive mini-kits for farmers. At Khumaltar, the tallest lines were NARC-1 (PAK), Bundel 851, PDLV G-5 (PAK), Canadian, Swan (PAK) and Awapuni. Tiller numbers varied from 5 to 6 per plant and leaf number per plant was in the range of 4 to 5. Days to Maturity ranged from 180 to 212. Early cultivars were Kent, 346/2, 323/02, Swan (PAK), and Swan (NEP); medium maturity were Canadian, PDLV-G5 (PAK), and Bundel 851, and late cultivars were NARC-1 (PAK), 83 INC 19 G3, CDA 1001, Awapuni, Taiko, Omihi, Charisma and Caravelle.

Green matter and grain yields differed from station to station, and whether irrigated or rainfed. Average green matter yield ranged from 10.3 t ha^{-1} for Omihi to 60.9 t ha^{-1} for 346/2 in Khumaltar, whereas in Tarahara (Terai; 70 m) the lowest green fodder yields were from Bundel 851 (27.8 t ha^{-1}) and 323/02 (28 t ha^{-1}), while the highest yielder was Kent (40 t ha^{-1}). In Pakhribas, Lumle, Rasuwa, Nepalgunj and Parwanipur, the highest yielders were Caravelle (38 t ha^{-1}), Caravelle (17.9 t ha^{-1}), Bundel 851 (17.1 t ha^{-1}), PDLV-G5 (16.8 t ha^{-1}) and Kent (20.9 t ha^{-1}).

In Khumaltar, the highest seed yields were from Swan (NEP) (3.9 t ha^{-1}), NARC-1 (PAK) (2.5 t ha^{-1}) and Caravelle (2.4 t ha^{-1}). In Tarahara, Kent produced 3.2 t ha^{-1} and Caravelle 2.1 t ha^{-1}. In Pakhribas, the cultivars with the best seed production potential were Amuri (2.2 t ha^{-1}) and Caravelle (2.0 t ha^{-1}). In Lumle, Rasuwa and Nepalganj, the best

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Figure 7.4
Oat trials at Khumaltar, Nepal

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Figure 7.5
Oat cultivars from New Zealand under evaluation at Khumaltar, Nepal

potential grain yielders were Bundel 851 (3.36 t ha^{-1}), Awapuni (4.4 t ha^{-1}) and Kent (2.7 t ha^{-1}).

Quality assessment of cultivars

Farmers' have reacted very positively to oats because of their high forage yield; in

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Figure 7.6
Seed storage at Khumaltar Research Centre

winter, all farmers report increased milk yield from feeding green oat forage. In 1989–90, oats from eleven sites in the Koshi Hill Command Areas in Pakhribas (1 020 to 1 650 m) were analysed, as were fifteen cultivars in Khumaltar in 1996. In both cases, crude protein contents at pre-bloom were above 7 percent (except from Awapuni, PDLV (PAK) and NARC-1 (PAK)).

How farmers grow fodder oats

Oats are grown in different ways in the various agro-ecological situations. The commonest situations are described below.

Oats on khetland (irrigated) in the Terai

Two ploughings are given after paddy harvest in the second week of November; rich farmers use tractors, substantial farmers use the animal-drawn *desi* plough (which works to a depth of 30 cm). Farmyard manure (FYM) at 7 tonne per ha and urea are then broadcast; the total amount of urea is divided into the number of cuts to be taken, and all the FYM is applied as a basal dose. If four cuts are to be taken, then 25 kg urea are applied as the basal dose along with FYM. Seed is broadcast at a rate of 100 kg ha^{-1} in the fourth week of November. The first cut is generally taken after a month; the amount cut daily depends on the number of animals. When half of the field is harvested, urea is applied, according to the size of the plot, and irrigation given. By the time the second half is cut, the first half is ready to be harvested again. Fodder oats can be harvested up to April.

Oats on khetland in the Low hills

After paddy harvest in the third week of November, one ploughing is done by local plough to about 23 cm and FYM broadcast at 5 t ha^{-1}. After a second ploughing, 50 kg ha^{-1} of urea is applied, split into basal and other doses depending on the number of cuts to be taken, and 120 kg ha^{-1} of seed is broadcast in the first week of December, in furrows left by the local plough, followed by a heavy plank to level the land and ensure the seed has good soil and moisture contact. A first cut is taken in the second week of January (50 days after sowing); subsequent cuts are at 40-day intervals. Split doses of urea are applied after each cut and irrigation given.

Oats on bariland (rainfed) in the Low and Mid-hills

Maize is harvested in the last week of August; a ploughing is then done to eradicate weeds and maize roots; FYM is applied at a rate of 7–10 t ha^{-1} and a second ploughing prepares the land thoroughly, mixes in the FYM and levels the field. Seed is broadcast at 120 kg ha^{-1} in the first week of September and a spade is used to ensure good seed contact with soil and moisture. The first cut is generally in the first week of November (60 days after sowing), with subsequent cuts at 45-day intervals.

In all areas, if seed is to be harvested, only a single fodder cut is taken.

Oats can be grown in summer in the Mid-hills but experience with summer oat growing at high altitudes has not, however, been positive. While the crop can grow well, if clean weeded, the challenge from summer-growing weeds is so severe as to render oat growing at that season very laborious and of doubtful success.

Oat growing in different areas

Once it was well established that fodder oats produce nutritious fodder in winter, the Department of Livestock Services initiated oat cultivation in all seventy-five districts of the country through distribution of mini-kits for winter fodder: oats alone and in mixture with vetch (both *Vicia benghalensis* cv Popany and *Vicia villosa* var. *dasycarpa* cv Nemoi were used), pea (*Pisum sativum*) or berseem (*Trifolium alexandrinum*), depending on suitability for particular areas.

At the same time, research focused on resource-poor farmers and commercial dairying areas. There were two major farm issues to be addressed:

- shortage of fodder in the dry winter (December to April), and
- high cost of producing milk.

Resource-poor farmers in Nepal are the group who have less than 0.5 ha of land, but keep one to two milch buffaloes and whose main livelihood comes from milk sales to urban areas.

Field studies identified an additional problem: the low oat yield per unit area in farmers' fields. Kshatri, Chejong and Rai (1993) stated that the average oat forage yield by farmers in the eastern hills was between 18 and 22 t ha^{-1}, which is much less than the 60 t ha^{-1} claimed in a similar Indian context (Pathak and Jukhmola, 1983). On five sites of the Farming Systems Research Command areas, oat cultivars such as Amuri and JHO 822 produced an average fodder yield of 15.5 t ha^{-1}, and Swan yielded 18 t ha^{-1}. These yields were obtained by the farmers with 80:40:20 $N:P_2O_5:K_2O$ fertilization and a two-cut management system. Although yields differed from one location to another due to environment and manage-

TABLE 7.14
Description of the sites involved in the farming systems research, Nepal

Parameters	Khandbari	Naldung	Pumdi Bhundi	Kotjahari	Patan Baitadi
Rainfall (annual average)	1200 mm	n.a.	4000 mm	1390 mm	1559 mm
Temperature (annual average)	8–34°C	n.a.	8–20°C	n.a.	n.a.
Farming situation	Lowland – partially irrigated	Lowland – partially irrigated	Completely rainfed	Lowland – fully irrigated	Lowland – fully irrigated
Villages covered	Mankamasna Pangma Malta	Chisapani Baluwapata Gairigaun Mesogaun	Pumdi Bhundi	Kotgaun Kumaigaun Khatrigaun Javre	Patan Baitadi
Dominant cropping patterns	R-W-F R-F	R-W-F R-F-F	R-F-mustard R-W-mustard	R-W-mustard	Maize-W R-W–F

KEY: R = rice; W = wheat; F = fallow; n.a. = not available

ment, the overall production of fodder oats on farmers' fields was unsatisfactory. The low yields were probably due to poor husbandry, including late sowing, and have since improved greatly, as described below.

In the Low Hills, production was reported to be 15–20 t ha^{-1} from three cuts, and in the Terai it was 20–25 t ha^{-1} from three cuts. Average on-farm seed production is not known, so it is difficult to estimate the seed needs of the Department of Livestock Services.

Farming system research

Oats as a pure crop and in mixture with vetch was introduced to five resource-poor farmer sites in the Mid-hills. In Pumdi Bhumadi, cvs Amuri and JHO 822 both produced an average of 15.5 t ha^{-1}. In Kotjhari, cv. Kent+vetch produced 19.4 t ha^{-1} and cv. Swan+vetch yielded 20.6 t ha^{-1}. In Khandbari, oats were tested at an altitude of 1 675 m and the yield observed from cv. Swan was 18 t ha^{-1}. At Patan Baitadi sites, the Kent+vetch combination gave a yield of 28.7 t ha^{-1}, whereas in Naldung, the Swan+vetch combination gave an average yield of 20 t ha^{-1}. All trials received 80:40:20 (N:P_2O_5:K_2O) fertilizer application under a two-cut management (Table 7.14).

Oats on leasehold group sites

A new system of management was used for leasehold[3] farmers' group sites in both the low and transitional belts: one ploughing with a local plough was done after paddy harvest; FYM at 5 t ha^{-1} was broadcast uniformly; and another ploughing done. The recommended dose of fertilizer was 80:60:40 kg (N:P_2O_5:K_2O). Nitrogen was given in three doses, after each cut, under irrigated conditions; as a single basal dose under rainfed conditions (fertilizer was applied in the furrows, covered with a thin soil layer and seed was sown immediately on the same line and smoothly covered). After sowing, a land leveller was used to ensure good seed contact with soil and moisture. Where oats were sown in mixtures with vetch or pea, the legumes

[3] "Leasehold" in this context refers to the Hills Leasehold Forestry Scheme, wherein landless farmers receive degraded forest land, on a lease, and undertake to improve its management. Fodder is a major component.

were first inoculated. The first cut was taken after 45–50 days, and subsequent cuts at 30-day intervals.

In the low belt (400–1 200 m) of all leasehold districts, relatively larger amounts of green fodder were obtained from the oat+legume mixture than from pure crops of either. During 1996–98 at low altitudes, the average yields of oat+vetch, oat+pea and oat alone were 31, 27 and 25 t ha^{-1}, respectively. There was a tremendous increase in yield in 1999–2001, due to better management by the farmers and the realization of the contribution oats could make to milk yields (Table 7.15). Comparing the two methods, i.e. recommended (with fertilizer) regime and the original farmer practice (no fertilizer use), the recommended method gave more than twice the yield in both the Low Hills and the transitional belt.

In Makawanpur, the highest yield was obtained from oats+vetch; in Kavre, from oats+berseem; in Sindhuplanchowk, from berseem; in Ramechap, from oats+peas, and in Dhading it was oats+berseem. With usual farmer practises for manure application (control), the treatments that gave the highest yields were oats+vetch, berseem, oats+vetch and oats+vetch in Makwanpur, Kavre, Sindhupalchowk, Ramechap and Dhading, respectively. This suggests that at low levels of fertility, the oats+vetch combination performs best (Table 7.15).

In the transitional belt, with recommended practices of manure and fertilizer application, oats+vetch, oats+vetch, oats+vetch, oats and oats were the highest yielders in Makawanpur, Kavre, Sindhupalchowk, Ramechap and Dhading, respectively. However, with the control treatment of only manure application, oats+vetch, oats+pea, oats+vetch, oats and oats were the highest yielders in Makawanpur, Kavre, Sindhupalchowk, Ramechap and Dhading, respectively (Table 7.16).

TABLE 7.15

Average green matter yields (t ha^{-1}) for various crop combinations (fertilized and unfertilized) in Makwanpur, Kavre, Sindhupalchok and Ramechap (1996–98) and in Makwanpur, Kavre, Sindhupalchok, Ramechap and Dhading (1999–2001) in the low belt (400–1200 m)

	With fertilizer		No fertilizer	
	1996–1998	1999–2001	1996–1998	1999–2001
Oats+vetch	31	41	14	26
Oats+pea	27	41	13	22
Oats	25	31	12	18
Oats+berseem	-	40	-	22
Berseem	-	33	-	19

TABLE 7.16

Average green matter yields (t ha^{-1}) for various crop combinations (fertilized and unfertilized) in Makwanpur, Kavre, Sindhupalchok and Ramechap (1996–98) and in Makwanpur, Kavre, Sindhupalchok, Ramechap and Dhading (1999–2001) in the transitional belt (1 200–1 800 m)

Crop	With fertilizer		Without fertilizer	
	1996–1998	1999–2001	1996–1998	1999–2001
Oats+vetch	18	31	10	17
Oats+pea	14	29	8	17
Oats	16	29	8	17

Oat seed production from Leasehold Group sites

To provide seed and generate income, seed production was organized with leasehold farmers (Figures 7.7 and 7.8). During 1996/1998, the highest average seed yields were obtained in Ramechap. In Kavre and Sindhupalchok Districts, all three treatments produced a consistent level of seed. In Makawanpur, oat as a pure crop produced as much as 3.6 t ha^{-1} of seed. In Ramechap, oats+vetch mixture gave 2.6 t ha^{-1} of oat seed.

During 1999–2001, five districts in the low altitude (400–1 000 m) and transitional belts (1 201–1 800 m) were selected for seed production of oat, vetch, pea and berseem (low altitude belt) and oat, vetch and pea in the transitional belt. In the transitional belt, yields of oat seed were 1.82–5.3 t ha^{-1}; vetch yielded 0.12–1.1 t ha^{-1}; pea yielded 0.02–0.5 t ha^{-1}; in the low belt, the highest yields were: oats, 3.7 t ha^{-1}; vetch, 1.1 t ha^{-1}; pea, up to 0.7 t ha^{-1}; and berseem, 1.1 t ha^{-1}.

Oats in commercial dairy pockets

A continuous programme of dairy farmer-oriented research to upgrade the feed situation in dairy pockets has been conducted in six districts (Pariyar *et al.*, 1996, 1999). During 1996–98, dairy pockets selected for integrated research were in Rupandehi, Kaski and Illam districts, and in Kavre (Figure 7.9), Dhading and Rautahat in 1999–2001.

Two trials were carried out (one involving eight promising oat cultivars and the other oats mixed with vetch (*Vicia dasycarpa*) and pea (*Pisum sativum*) from 1996 to 1998 in Rupendehi (500–600 m), Kaski (800–850 m) and Illam (1 500–

Figure 7.7
A good oat seed crop, Dhading

Figure 7.8
Spreading oats to dry, Dhading

Figure 7.9
Oats cut for fodder in Dhading

TABLE 7.17

Average green matter yield (t ha^{-1}) of pure oat stands in dairy pocket areas of Rupendehi, Kaski and Illam (1996–98) and Kavre, Dhading and Rautahat (1999–2001)

Cultivar	With recommended fertilization(1)		With traditional farmer practice(2)	
	1996–1998	1999–2001	1996–1998	1999–2001
Caravelle	27	69	19	41
83 INC 19 G3	26	59	19	39
Canadian	26	68	19	48
Awapuni	26	61	17	35
Charisma	24	60	18	41
Taiko	27	59	21	39
Kent	27	60	20	38
Swan	26	58	19	39

NOTES: (1) 5 t FYM ha^{-1} + N:P_2O_5:K_2O at 80:60:40 kg ha^{-1}. (2) ca 5 t FYM ha^{-1}.

TABLE 7.18

Average green matter yield (t ha^{-1}) of oats and oat+legume mixtures in dairy pocket areas of Rupendehi, Kaski, Illam (1996–1998) and Kavre, Dhading and Rautahat (1999–2001)

Treatments	With recommended fertilization(1)		With traditional farmer practice(2)	
	1996–1998	1999–2001	1996–1998	1999–2001
Oat+vetch	36	52	24	36
Oat+pea	33	45	21	38
Oat	27	46	19	35

NOTES: (1) 5 t FYM ha^{-1} + N:P_2O_5:K_2O at 80:60:40 kg ha^{-1} for oats in pure stand; 5 t FYM ha^{-1} + N:P_2O_5:K_2O at 20:60:40 kg ha^{-1} in mixtures with a legume. (2) ca 5 t FYM ha^{-1}.

1 550 m), and from 1999 to 2001 in Kavre (890–1 020 m), Dhading (810–840 m) and Rautahat (500–550 m). With the recommended treatment (5 t FYM ha^{-1} + N:P_2O_5:K_2O at 80:60:40 kg ha^{-1}), all cultivars yielded more than under traditional farm practice (5 t FYM ha^{-1}). Similarly, although environmental and management factors play a major role in fodder production, higher yields were obtained in subsequent years (Tables 7.17 and 7.18).

Results in farmers' fields over the six years (1996–2001) indicate that growing oats alone was not profitable. At all sites in the six districts, oats+vetch was outstanding in terms of green fodder production under both management practices.

Impact

Since the inception of the two livestock development projects, the popularity of oats has increased very substantially, and this has been boosted by the major thrust given by government to milk production. With the increase in irrigation projects, the formation of dairy development enterprises and cooperatives at village level by the Department of Livestock Services and National Dairy Development Corporation, and with the creation of the National Dairy Development Board, there has been increased emphasis on improved milk breeds and an intensification of oat growing. More and more wheat areas have been converted into oats, oats+vetch and berseem. According to the Department of Livestock Services, the growing of oats, vetch and berseem have considerably increased. Pande (1997) states that, before the 1980s, fodder cultivation was confined to 36 ha of arable land. Because of its economic impact on the milk industry,

TABLE 7.19
Estimated extent of oats+vetch and berseem cultivation in Nepal, 2001

Development Region	Oat seed(1) (kg)	Vetch seed(1) (kg)	Area(2) (ha)	No. of households	Berseem seed(1) (kg)	Area coverage(2) (ha)	No. of households
Eastern	15 695	670	164	3 280	734	29	290
Central	27 100	2 640	297	5 940	2 020	81	810
Western	146 070	2 145	1 490	29 800	1 260	50	500
Mid-Western	9 730	290	100	2 000	701	28	280
Far-Western	11 675	460	121	2 420	116	5	50
Total	210 270	7 005	2 172	43 440	4 831	193	1 930

Notes: (1) Official seed distribution through District Livestock Development Offices. Home-saved seed and farmer-to-farmer seed sales are not included in this estimate. (2) Area sown derived by estimation from typical seed rates, namely oats+vetch, 100 kg ha^{-1}; berseem, 25 kg ha^{-1}. Berseem area per household assumed to be 0.1 ha. Oats area per household assumed to be 0.05 ha.
Source: DLS, 2001.

particularly in the Terai and Low Hills, some 2 000 ha of land were under winter fodder in the 1980s.

The Livestock Master Plan (1993) estimated that oats and berseem were grown on about 4 400 ha in the Terai and Midhills; the accuracy of this estimate is questionable, so the Department of Livestock was requested in 2001 to assess the current status of land under oats; information is summarized in Table 7.19. Data are included from five Development Regions, for oats, vetch and berseem seed distribution. Seed distribution was through the District Livestock Development Offices and the areas growing oats+vetch and berseem estimated. The cultivated land in the country is 3 052 000 ha of which 0.08 percent is under winter fodder. Oats and vetch occupy 0.07 percent (2 172 ha) of all cultivated land. However, use of home-saved seed and farmer-to-farmer seed sales are not included in this estimate, so the true area could be greater, and could exceed 3 500 ha.

Other important virtues of the oat crop are its multicut nature, green fodder availability in winter (December–April) and its direct impact on maintenance of milk production. Feeding trials on the effect of oat feeding on milk yield indicate that considerable increases could be obtained by feeding 6–8 kg of green oats daily per milking buffalo. The daily average increment ranged from 0.3 to 0.45 litres in the command area of Lumle.

A survey by the Department of Livestock Services on forage-based milk production in the peri-urban areas of Illam indicates that the production cost of one litre of milk is around rupees (Rs) 10.0[4], whereas in urban areas with concentrate+paddy straw feeding, the cost of one litre of milk was about Rs 18.0. Also, for resource-poor farmers, oat cultivation has resulted in a net profit of Rs 1 538 per animal per month per arable land area of 0.075 ha.

A study in Kavre (Pariyar, 2000) showed that oats+vetch mixtures increased milk production by 30 litres per buffalo per month, on average, while the demand for purchased concentrates was reduced by 30 kg per month and milk production was extended by 8 weeks. This resulted in an additional net profit of Rs 1 538 per month, where, on average,

[4] At the time of the study, the exchange rate was US$ 1 = Rs 76.

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Figure 7.10
Oat cultivars under evaluation at Dhunche Agricultural Research Station, Nepal

the cash income of families was Rs 2 000 (over a four-month period).

Better utilization of fallow is another important use of oats, as some land that used to lie bare after paddy harvest is now used to grow oats. There are therefore strong economic reasons why the area under winter fodder has increased every year.

Further work needed

Cultivars for higher altitudes (3 000–3 800 m)

Fodder oats are being adopted up to around 2 000 m (e.g. Khimti at 1 994 m), but large-scale cultivation is in commercial dairy pockets, and among resource-poor farmer areas of the Terai and Low Hills up to 1 600 m. Research has started in areas up to 3 250 m – based at Chandanbari sub-centre of the Agriculture Research Station, Dhunche (1 950 m) (Figure 7.10). There has been a lack of suitable oat cultivars for very high altitudes, but two varieties of *Avena nuda* have been imported under an FAO-assisted project; naked oats originate, and are widely grown on, the nearby Tibetan Plateau, so it is hoped that they will suit high altitude sites in Nepal.

Germplasm

Twenty oat cultivars were in use in Nepal in 2003. All are multicut and have become naturalized. So far, there has been no systematic breeding for better and higher fodder yields. Cultivars are identified and selected on the basis of their performance in multilocation trials, and new germplasm capable of giving high yields and good quality forage is needed for testing. There are some native fodder oat varieties in different parts of the country (Terai, Mustang, Rasuwa, etc.), which should be selected, evaluated

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Figure 7.11
Riayale test site, with oat cultivars grown by a woman farmer. Cv. Awapuri in middle, with controls cv. Swan (to left) and cv. Kent (to right)

and conserved (so that native germplasm is not overlooked). New cultivars have been acquired under the FAO project for testing in 2003–05 in different ecozones (Figure 7.11), with the main requirement being that they should need only minimum inputs for optimum production!

Oats in summer

Oats can be grown for green fodder as well as grain in summer in Dhunche, Rasuwa (1 950 m), but experience has shown that at lower elevations oats in summer are seriously hampered by weeds; above this altitude, more research is needed. In high areas at about 3 500–3 800 m, the aim would be to grow oats in summer for hay. More studies are needed on oats as a summer crop at high altitude sites, with new introductions to address a particular farming system.

Green oats to straw ratio

Ways of feeding green oats differ between the two main groups of farmers: resource-poor farmers grow oats on small areas (250 m^2) while commercial dairy farmers have larger areas (1 500 m^2). The area grown varies with herd or flock size and market opportunities. Resource-poor farmers feed green oats with rice and wheat straw (Figure 7.12); commercial farmers chop oats, before mixing with paddy and wheat straw. Therefore, further work is needed to establish the most economical ratio for green oat+straw mixtures to reduce concentrate feed cost or to increase milk production, or both.

Proper use of oat grain

In some parts of Nepal (Illam in the extreme east), boiled oat grain is fed to milking cows. This is very useful for

Figure 7.12
Buffaloes being fed a mixture of oats and straw, Kavre

Figure 7.13
Small-bag (ca 6 kg) silage – two months old and ready to feed to livestock

increasing milk yields, but the processing of oat grain for human consumption has yet to develop for feeding the poor and for increasing food security.

Problems

Oats extract, like other fodders, more soil nutrients than are currently being returned to the soil by resource-poor farmers (with manure typically applied at ca 5 t FYM ha^{-1}); also, growing oats in winter has tended to hamper the succeeding crop (cereals, potatoes, etc.). Most fodder oats are fed green by the cut-and-carry system. Early, medium and late cultivars have been introduced and are being evaluated in high altitude areas.

Conservation as hay and silage is very rare. In the Terai, the Low Hills and part of the Mid-hills interest will mainly be for oats for green feed since other green forages are available in all seasons to supplement relatively plentiful crop residues; at higher sites, however, there is a need for conserved fodder. Haymaking is being developed, and silage making using small plastic bags (Figure 7.13) is very promising; this was widely and successfully tested under the Second Livestock Development Project (see Lane, 2000) and the technique has been modified to reduce the danger of rodent damage to filled bags.

Chapter VIII
Fodder oats in China

Shu Wang

SUMMARY

Oats have been cultivated in China since prehistoric times, and the country is a centre of oat diversity. Currently, oats rank tenth among cereals in terms of production, and oats are an important fodder crop in the nation, grown in eighteen provinces and regions in China. Although there are several wild and cultivated Avena species, the two major two types are hexaploid hulled and naked oats (*Avena sativa* L.). China is one of the major oat-producing countries in the world, with an annual harvested area of 350 000 ha, yielding 465 000 t, an average yield of 1.33 t ha^{-1}. With the development of China's agriculture and livestock husbandry, oats are becoming a promising fodder crop in the areas where climate is favourable, especially in the remote, cooler mountain areas.

BACKGROUND

Oats have been grown in China for approximately 2100 years, according to *Shi Ji* [Historical Records], a book by Si Matsian (145–87 BC). Few details are known about the origin of Chinese oats, especially on their migration to central and eastern Asia. Bretschneider (1881) stated that naked oats resulted from the mutation of hulled oats, and that hexaploid naked oats originated in China. Meanwhile, he identified this naked oat as *Avena nuda*. Stanton (1923) considered Central or Eastern Asia as their origin. Vavilov (1926) regarded China as their centre of origin.

Although wild species of oats can be found in some areas, compared with other oat-producing countries, the predominant form of Chinese oats has been the hexaploid naked type of *Avena sativa* (Yang and Sun, 1989). The name *Avena nuda* is sometimes used in local agricultural literature when discussing naked oats – but it is the naked form of *A. sativa* that is grown. This crop was cultivated as a staple cereal by the Chinese three decades ago and is still grown as food. Oat straw is of considerable value for roughage, bedding and for poultry litter, and the grain is an important feed for poultry and swine. Hulled types of *Avena sativa*, mostly introduced from western countries since the 1970s, are now becoming an important fodder as hay, silage and grazing for livestock in the cooler areas, where the thermal regime limits grain crops such as maize and soybean. The area sown to hulled oats was reported by Hu and Zhang (2003) to be 155 700 ha, in contrast with 118 700 ha of naked oats.

Production

Oat production in China since 1961 is shown in Table 8.1. Yield per unit area has increased greatly since 1974 with the release of high-yielding cultivars and the extension of improved cultivation methods. The total yield remained stable in the 1990s, but yield in 2003 was the lowest in 40 years, due to reduced area sown and the yield per unit area.

TABLE 8.1
Oat production in China since 1961

Year	Area ('000 ha)	Yield (t ha⁻¹)	Production ('000 t)
1961	1200	0.92	1100
1965	1200	1.0	1200
1970	1000	0.95	950
1975	700	1.29	900
1980	567	1.55	877
1985	499	1.78	890
1990	492	1.81	890
1995	502	2.0	1004
2000	370	2.74	1012
2001	350	2.26	790
2002	325	1.51	490
2003	350	1.33	465

Source: FAOSTAT.

TABLE 8.2
Ratio of areas and tonnages of cereals in China in 2003 compared with 1991

Crop	Ratio of areas	Ratio of tonnages
Oats	0.29	0.42
Wheat	0.86	6.02
Rice	1.01	2.98
Maize	1.55	6.33
Barley	0.249	0.84
Rye	0.35	0.39
Triticale	*30.8	*34.2
Soybean	0.95	2.63
Sorghum	0.12	0.46

Note: * cultivation was negligible before 1991.
Source: FAOSTAT

The area decreased sharply in 1974 and trend was still for decrease in 2002. During the last 40 years, the combination of maize and soybean, supplemented with minerals and vitamins, has become the standard diet for monogastric stock. The efficient production of both maize and soybean in China makes them ideally suited for efficient animal production. Maize has also been used successfully and efficiently to produce fodder. The increase in maize production has been largely responsible for the reduction in area devoted to oats.

Maize showed a big gain in area and an obvious increase in tonnage after 1960, with 23.52 million hectares grown in 2003 (Table 8.2). In some areas such as Qinghai and Tibet, where grain maize can not be grown with certainty, or where it is too expensive to import, barley and wheat are grown and used as an energy source by feed formulators. In China, many plant breeding and cultivation efforts have been made in the past half century to raise the productive capacity of wheat, usually with success, which has led to wheat overproduction. For a long time, the price of wheat was even lower than that of maize; therefore, some researchers began to study the feeding value of wheat grain (Wang and Zhao, 2001).

Wheat is not as well suited as maize for animal feed, especially for non-ruminants, because it contains less metabolizable energy. However, these cereals are grown extensively in cooler areas and used by feed manufacturers, especially when cheap. Their general availability during seasons of surplus production, or when poor weather conditions result in an oversupply of low-grade grains, has depressed the market for feed oats and led to a further reduction in oat area. Besides the influences of maize, soybean and wheat, the area increase in triticale is another factor, further reducing the area sown to fodder oats. The production of triticale has grown rapidly since 1991, and its area was 310 000 ha in 2003. Its cultivation did not start until 1975 in China, when 476 ha were planted (Table 8.2).

Nutritive value

In spite of the competition, oats are still grown in parts of China, although less than previously, and the grain, straw and forage still play useful roles in feeding domestic animals. Oats have a long and

TABLE 8.3
Comparison of composition of grain between naked oats and maize

Cultivar	Crude protein (%)	Total N (%)	Crude fibre (%)	Fat (%)
Naked Oat 323	19.58	3.13	6.82	8.78
Naked Oat 82	15.07	2.41	4.28	8.07
Maize	7.70	1.23	1.50	4.1

SOURCE: Zheng *et al.*, 2002.

TABLE 8.4
Oat consumption in China, 1960–1991 ('000 t)

Consumption	Period						
	1960–64	1965–69	1970–74	1975–79	1980–84	1985–89	1990–91
Feed	184.6	295.0	194.6	158.4	310.0	371.8	365.0
Food, seed and industry	757.4	619.2	525.8	561.2	443.2	314.8	300.0
Total	942.0	914.2	720.4	719.6	753.2	686.6	665.0

SOURCE: Welch, 1995.

satisfactory history as food and feedstuff. Both protein content and quality, as measured by amino acid composition, are well recognized and of particular importance when feeding non-ruminants. Zheng, Han and Yu (2002) compared two new naked oat cultivars, Naked Oat 323 and Naked Oat 82, with maize grain for four nutritional components in the summer growing area of Inner Mongolia. Table 8.3 shows the general composition of two naked oats in comparison with the maize used in animal feed.

A study was also conducted on feeding dairy cows with whole-crop oats harvested at heading stage, or a bit earlier, in contrast with silage maize. Because of oats' higher nutritive value compared with maize silage, each dairy cow could produce an additional 2.13 kg milk per day more, resulting in each dairy cow giving an annual extra return of US$ 225.36. In this area, growing naked oats is cheaper than handling silage maize, and therefore oats are an optimal crop, with dual use as cereal and forage. Breeders have tried to improve the amino acid composition of maize, barley and wheat proteins to increase their biological value, but oat protein is already quite rich in lysine because of its high globulin content. The lipid content of grain is largely unsaturated fatty acids, which, when fed, can alter the fatty acid composition of animal fat.

Economic importance

In China, since the 1960s, the proportion of oats used for feed has increased rapidly; it was double in 1990–91 compared with 1960–64 (Table 8.4). Generally, more than half of all oats are used as feed and another 40 percent for food and industrial use, with about 6.4 percent as seed. Oats used to be valuable feed for horses and mules; now the whole crop or the straw are mainly used as hay or silage for ruminants, while, the grain or groat are used for pigs and chickens. Grain yields vary from 2.4 to 3.8 t ha^{-1} in the better environments, but less at higher altitudes (over 3000 m). Green yields range from 10 to 30 t ha^{-1} and hay from 3 to 6 t ha^{-1} in Qinghai and Gansu provinces (Shi, Li and Li, 1999; Xu, 2003). Recently, the oat grain harvest was valued at US$ 61.92 million, equivalent to an average price of US$ 133.17 t^{-1}; straw was valued at US$ 16.88 million, or an average of

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Figure 8.1
Oats in Basang Region, Hebei Province

US\$ 24.21 t^{-1}; hay was valued at US\$ 2.59 million, or an average of US\$ 48.43 t^{-1} (Yang, Yang and Liu, 1998).

DISTRIBUTION

As a coarse grain, oats only take up 4.6 percent of total cereal areas distributed in 18 provinces and regions. However oats are mainly grown in ten areas: Inner Mongolia, Hebei, Gansu, Shanxi, Shaanxi, Yunnan, Sichuan, Ningxia, Guizhou and Qinghai. Of the total sown area, Inner Mongolia has 36.8 percent; Hebei, 20.7 percent (Figure 8.1); Gansu, 18.0 percent; and Shanxi, 14.7 percent. Oats are also sparsely distributed in other provinces, such as Heilongjiang, Jilin, Tibet (Figures 8.2a and 8.2b) and Xinjiang.

The concentration of oats in these four regions is firstly due to climate, as oats can produce higher yields than other crops. Secondly, animal husbandry is so developed that oats are an important feed resource. Because oats have extremely wide environmental adaptability they can be sown from mid-April to mid- or late June so as to alleviate stress damage occurring in early spring. In China, spring oats occupy more than 90 percent of the oat-sown area and produce 95 percent of the total production. The rest is weak winter oats. According to ecological conditions and farming system, as well as topography, China can be divided into two main oat distribution areas and four subareas (Yang and Sun, 1989).

Northern spring oat area

Northern early oat subarea

This subarea comprises the Tumote prairie of Inner Mongolia Autonomous Region and Datong and Yiding basins of Shanxi province. Altitudes range from 800 to 1 000 m. The annual precipitation is 300 to 400 mm, and fluctuates widely between

Figure 8.2a
Oat trials at Damxung on the high plateau at 4 300 m, Tibet Autonomous Region, China

Figure 8.2b
Oat trials at Damxung on the high plateau at 4 300 m, Tibet Autonomous Region, China

years and months. Irrigation is used in some places, providing crop yields that are much higher than without irrigation. The annual mean temperature is 4 to 6°C, with a maximum temperature of 35°C in June and July. Hot, dry weather during heading and ripening frequently lowers yields, so early-maturing varieties are grown in some sections. Hailstorms may cause damage locally. Diseases related to warm and wet weather often affect oat yields and quality. Sowing starts from early April and harvest is in mid- or late July; cultivars are characterized by early maturity, drought and cold resistance in this subarea.

Northern middle and late oat subarea

The northern middle and late oat subarea includes the central and western parts of Xinjiang Uygur Autonomous Region, Helan Mountain and Liupan Mountain of Gansu, mountainous areas along the Yellow River valley in Qinghai, northern parts of Shaanxi province, southern parts of Ningxia Hui Autonomous Region, Yin Mountain of Inner Mongolia, the northwestern plateau, Taihang and Lüliang Mountains of Shanxi, northern parts of Hebei, Yan Mountain of Beijing and southern Xing'an Ranges of Heilongjiang. Because of the mountainous character of this area, agriculture is confined to the river valleys, bench-lands and plateaux. This sub-zone has 80 percent of all the oat area in China; oats are grown at elevations between 500 and 1 700 m. Rainfall is very important in influencing production. The annual mean precipitation is 300 to 450 mm, with 70 percent falling during June, July and August. Because rainfall is relatively low in most sections, irrigation is used extensively where sufficient water is available. Temperature is also a very important factor. The annual mean temperature is 2.5 to 6°C. Soil type and fertility vary greatly. In many areas, oats are an important crop. In general, oat yields per unit area are higher in the irrigated sections than in most other parts of China. The quality of the oats is also excellent.

Southern winter oat area

Southwestern mountain late oat subarea

The southwestern mountain late oat subarea contains Big and Small Liang Mountains of Yunnan, Guizhou and Sichuan provinces, northern parts of Sichuan and Gaoligong Mountain of Yunnan. In many sections of this subarea, where little maize is produced, oats are one of the most important concentrate feeds for livestock. Oats are grown at elevations between 2 000 and 3 000 m. The annual mean temperature is 5°C. Mild winters throughout this zone permit the growing of autumn-sown oats. The annual precipitation is relatively high in most sections and averages 1 000 mm. The main yield-limiting factor is lack of sunlight throughout the growing season. The growth period covers 220–240 days as oats are sown in mid- or late October and harvested in late June or early July. The oat cultivars sown in this sub-zone are characterized by cold and drought resistance, but are susceptible to lodging.

Southwestern prairie late oat subarea

This subarea compromises the flat prairies of Big and Small Liang Mountains in Yunnan, Guizhou and Sichuan provinces. Climatic conditions are the same as the mountain late oat subarea. Owing to the relatively high rainfall, advanced irrigation facilities and

high soil fertility, this subarea is well known for high yields of oats. The growth period is 200 to 220 days. Naked oat cultivars with large kernels are sown widely.

Place of fodder oats in rotations and farming systems

In China, oats are grown primarily to complete rotations and to meet feed requirements of animals on-farm and grain for human food. However, as cropping systems vary greatly in different sections of China, the place of oats in rotations also varies greatly. According to ecological conditions, rotations can be divided into autumn-harvested oat zones and summer-harvested oat zones.

Autumn-harvested oat area

Because of the climate, the main crops sown in this area are spring wheat, oats, potatoes, sesame, rape and pulses; it can be further divided into dryland and humid sections.

Dryland section

Rainfed farming prevails in autumn-harvested areas with light soil fertility. Alternative crops in the farming system are extremely important to make the most advantage of soil to produce much more biomass and economic yield. In most sections where wheat and oats are the main crops, rotations often used include the following: pea–oat–potato + pea–wheat–sesame or rape; potato + pea–wheat–oat–sesame or rape; and potato–sesame or rape–pea–wheat or oat. In these rotations, cereals are the main crops and cash crops are minor ones. The ratio of the main to cash crops are 2 : 1 or 4 : 1.

In some drier areas, an alternative crop and fallow system is largely followed. The tillage methods used keep the soil rough and maintain crop residues on the surface to prevent wind erosion and water runoff. Oats must be sown early in spring for good yields. Thus, they are usually sown on fallow of the dry lands or follow an inter-tilled crop that leaves the soil in condition to be prepared quickly for spring sowing. In sections having more farmland and sparse population, a system with rotating green manure is followed, together with the fallow system. Rotations used in these sections are: green manure crop (e.g. lucerne (*Medicago sativa*))–wheat–oats–sesame or rape; or green manure crop–oats or wheat–potato–sesame or rape.

Humid section

In this section, oats are considered a main crop and take up 70 percent of the sown area. A decade ago, continuous cultivation of oats might be extended to four or seven years because of lack of labour, limited mechanization and lack of knowledge of rotations, thus limiting oat productivity. In recent years, wheat, broad bean and other crops are planted together with oats. Two common rotations for this section are: wheat–broad bean–oats; and broad bean–oats–wheat–potato + sesame + rape. In some areas of subtropical Guizhou, oats can be sown in paddy fields once rice is harvested and can be cut several times in winter and early spring for use as green feed (Luo, Mo and Long, 2000).

Summer-harvested oat area

Unlike the autumn-harvested oat area, ample heat and rainfall permit this area to grow heat-favoured crops such as maize, sorghum, millet and sugar beet. Because maize, sorghum and sugar beet

Figure 8.3
Oats and wild pea (vetch) mixture, Hebei Province, China

are fertility-exhausting crops, in contrast with fertility-saving crops such as wheat and oats, the alternate cultivation of crops of each type probably gives the greatest return for the least expenditure of labour of any in this area. In some sections. oats produce more when grown after maize than after any other crop. Sugar beet may also follow oats in a four-year rotation of maize, oats, beet and wheat. Anyway, because a preceding crop has less influence on oats than on wheat or barley, most rotations are arranged to meet the special requirements of other crops and oats usually occupy the least favoured phase. The adaptability of oats allows it to work well in almost any rotation.

In recent years, it has been reported that oats are often used as a companion crop for maize, pea and vetch. Wu and Ge (1999) reported that in Lingtai irrigated area of Gansu, bare land in maize fields lasts 80 days before maize begins to grow fast, so oats intersown with maize can yield 46 861 kg ha^{-1} of green feed in mid-June and the maize yield is not affected. Han *et al.* (1999) and Ma, Han and Mao (2001) studied the optimal harvest time in both monoculture and mixture of oats and pea in the northwestern parts of Hebei (Figure 8.3).

Results indicated that the late milk and early dough stage of oats and the pod-filled stage of pea in the mixture were the best harvest time based on the highest crude protein (CP), good dry matter (DM) yield, lower acid detergent fibre (ADF) and lower neutral detergent fibre (NDF) contents. Some reports stated that in order to get high forage and high protein yield, the best ratio of oats to legumes such as vetch or pea is 5 : 5 or 6 : 4 in the

mixture system used in mountain areas of Qinghai, Gansu and Hebei provinces (Han, Che and Zhou, 1992; De and Xu, 1998; Han and Ma, 1998; Ma, Han and Li, 1999; Bao and Zhang, 2002).

Catch cropping of oats mixed with vetch after the first summer harvesting crop have been reported by Sun, Lu and Ma (2003) in the highland region of Gansu, where wheat is a main crop. After the wheat is harvested, some light and heat resources can be used wisely to plant fodder oats and legume forage, which can produce 27 262 to 31 702 kg green forage ha^{-1}. However irrigation is needed to guarantee a harvest of high-yielding forage.

USE OF OATS

Oats for hay and grazing

A considerable area of oats is cut for hay in north China, especially in northwestern areas, where oats produce heavy hay yields used as emergency or supplementary hay for winter and early spring. In unfavourable seasons, or when prices drop, oats sown for grain are often cut for hay. When grown especially for hay, oats are frequently sown in mixture with field peas or common vetch. Oats at the milk or early dough stage make excellent hay. When cut at this stage and properly cured, oats make very palatable and highly nutritious hay that is relished by all classes of livestock. The addition of peas or vetch usually increases the yield of hay and improves its nutritive quality (Han *et al.*, 1999; Ma *et al.*, 1999; Kou *et al.*, 2003).

Cultural methods for growing oat hay are similar to those described for grain production. When sown mixed with peas, a common proportion is 75 kg of oats and 75 kg of peas per hectare. For the oats+vetch mixture, the proportion is 75–90 kg of oats and 50–75 kg of common vetch per hectare (Han *et al.*, 1999; Ma *et al.*, 1999).

Hay from oats alone or from oats grown in combination with other crop is made similarly to other hay. The cultivars of oats commonly grown for grain in most sections are most satisfactory for hay. In sections where both short-straw early and the taller-straw mid-season cultivars are grown, the taller cultivars are preferable, because of the heavier yield of forage.

Because of the nature of their root system, oats will not stand much continuous grazing, and care must be taken to avoid overgrazing and excessive trampling. For grazing, oats may be sown at different times in summer if such feed is required throughout the season, since oats may be grazed four to five weeks after seeding. For grazing, the seed rate should be slightly heavier than for grain production. Cultivar choice is very important in that certain cultivars are better able than others to produce abundant leaves and tillers, and consequently to provide greater yields of forage. Some cultivars have the ability to recover more quickly than others after having been grazed. Rust-resistant cultivars are preferable in wet and warm areas during summer.

Oats for silage

Oats, sown in mixture with legumes such as vetch, are used extensively for silage. Frequently this is more profitable than when the oats are harvested for grain. Duo *et al.* (2002) tested the content of lactobacillus in oat wrapped silage and oats+vetch mixture wrapped silage. The results showed that the content of

lactobacillus in the two wrapped silages was similar in winter, but increased at different rates in spring. The content of lactobacillus increased more in the oats wrapped silage than in oats+vetch mixture wrapped silage mostly because of much higher water content in vetch. Oat silage is an excellent feed for cattle, especially dairy cows. A special advantage of oat silage is that it is available much earlier in the season than is maize or sorghum silage, and thus provides supplementary feed in the late summer months, when pasture is often in short supply.

The most favourable stage for cutting oats for silage is when the kernels are in the soft dough stage and most of the leaves are still on the stalk. Cutting oats for silage gets the crop off the field about two weeks earlier than when cut for grain. Traditionally, the guidelines for making oat silage include wilting to 60–65 percent moisture, short chopping and consolidation in the silo (Sun, Wei and Zhang, 2003). In recent years, a new package technique has become widely used in Qinghai province (Xue *et al.*, 2000), involving cutting oats for silage, then making them into small piles, and each pile is then made into an individual package using a grass wrapper. Each package, weighing about 40 kg, is wrapped in IPEX plastic film and stacked. The quality of the packaged oat silage is superior to oat hay, ranging from fair to good.

Use of straw

Oat straw has a high fibre content, which is extensively lignified, so it is poorly digested by monogastrics and its use is restricted to ruminant diets. Oat straw is, however, softer and more acceptable to herbivores than other straws and appears to be of good nutritive value. In China, most oat straw is from naked oats after threshing.

It has been long known that the digestibility of highly lignified materials may be improved by physical and chemical treatment. Treatment of straw with aqueous ammonia has been used for a long time in pastoral areas of China and has been proven to increase the crude protein content, intake and digestibility when fed to ruminants (Han and Ma, 1998). The solubility of NH_3 in water is strictly dependent on the temperature. At normal pressure, 1 kg ammonia solution can hold 285 g at 30°C and 342 g at 20°C. Solutions containing 25–35 percent ammonia are common. The solution, sufficient to give 3.0–3.5 percent NH_3 in the straw, is injected into stacks through a tube mounted in a metal pipe. To ensure proper distribution, the ammonia may be injected at several points of a stack. In cold areas, if the temperature is low, treated straw is stored in a greenhouse for a recommended six to eight weeks. If curing is done early, when the temperature is high, two to three weeks may be sufficient.

FEEDING OF OATS

Oats for cattle

In China, oats are fed mostly in the form of hay, straw, green chop and silage. Luo, Mo and Long (2000) found that cattle fed on a mixture of oats and legumes could gain weight by 261 g day^{-1} more than those fed on rice straw. In northwestern areas, farmers often use oat as an emergency feed when perennial forages have failed because of winterkilling. Most oat cultivars have been bred for dual-purpose use as forage and grain. Oat straw is often used as bedding and feed

for overwintering beef cattle. Oats have been an important feed for dairy cattle over the years, but the amounts of grain used have decreased sharply as maize silage, grain maize and barley have gained predominance. Zheng *et al.* (2002) found that oats increased milk production in dairy cows compared with maize silage, so oat haylage is still used extensively in some areas. Oat-based diets increased the portions of unsaturated fatty acids in milk fat that are reported to be beneficial in human diets.

Oats for poultry

Oats have been well known for a long time as a good poultry feed, especially on the farm, but a major constraint is the hull, which is low in digestibility and contains little available energy and protein. When oats are used in balanced diets, the grain is ground before use, thus increasing the cost. However, evidence shows that naked oat cultivars give good results as a feed for broilers and laying hens.

Oats for yak and sheep

In recent years, due to the adjustment of production structure, some areas of Qinghai and Gansu provinces changed from raising horses and mules to raising cattle, sheep and yak. Before mid-November, when slaughter begins, the natural pasture becomes withered. Lei (1999) reported that feeding 3 kg of freshly cut oats daily to yak for 35 days could increase weight by 12.9 percent and commercial meat grade by 16.0 percent. Dong *et al.* (1998) studied the ratio of digestion of several forages in yak rumen, using the nylon bag method, and found the best hay was oats. The ratios of DM and NDF were 54.1 percent and 39.5 percent, respectively. Other researchers studied the weight-increasing effect of pure oat hay, oats+vetch mixed hay and wheat straw in sheep: oats+vetch mixed hay provided a gain of more than US$ 4.17 per head, and pure oat hay could provide a gain of more than US$ 2.34 per head compared with wheat straw (Wang, Zhou and Wang, 2002).

NAKED OATS

Naked oats, so called because the kernels thresh free of the hulls, are recorded as having been grown and used as food in China 2 100 years ago; they are grown by farmers who find it advantageous to grow oats that can be fed to young stock and poultry without being ground, and can also be used as porridge or other food for humans. The recognition in recent years of their medical value may encourage farmers to grow more naked oats. Interest in naked oat is growing, and feeding experiments substantiate their excellent feeding value both as a source of energy, which is similar to maize, and as a source of high-quality protein, which is similar to soybean for poultry and pigs. Lysine supplementation may be required, but it can be easily included in the vitamin and mineral premixes. The groat also supplies unsaturated fatty acids that apparently contribute to the production of higher quality eggs, milk and meat products.

The successful breeding and utilization of naked oat will have a profound effect on the rearing of both ruminant and non-ruminant animals. Removal of the hulls genetically, so that the grain is as free-threshing as wheat, is probably the last major step in the domestication of oat. The benefits will probably be first realized on-farm, but, later, naked oat will

be accepted more by the food industry and diet formulators and become a grain of commerce, especially in cool regions where maize and soybean cannot be grown successfully because of low temperatures. This will provide farmers with a cash crop they can use in rotations and will provide many regions of China with an opportunity to become more self-sufficient in feed grains.

Normally, the best cultivars of naked oats yield slightly less than the better hulled cultivars, even when allowance is made for lack of hull. The lack of high yielding, well adapted, disease-resistant cultivars, together with a tendency to shatter when ripe and the danger of heating in storage, undoubtedly limit the increase of naked oats in China. This is possibly why a decade ago naked oats were predominant in China, but now the areas of naked and hulled oats are almost equal. Fortunately, oat breeders are making efforts to incorporate desirable genes from hulled oats into naked ones. A series of naked-type oats have been produced after hybridization between naked and hulled oats (Sun, Lu and Söndahl, 1991).

DISEASES OF OATS AND THEIR CONTROL

Diseases of the oat crop in China cause annual losses of millions of dollars. Some of these diseases may be avoided completely, or considerably reduced by seed treatment, good soil management, proper crop rotation, or by growing resistant varieties. Most diseases depend on a particular set of environmental conditions for suitable development. In some regions, certain diseases rarely appear, partly because of isolation from sources of infection or because of an unfavourable environment. Of the many diseases that attack oats, the smuts, rusts and Barley Yellow Dwarf Virus (BYDV) are the most common and cause the greatest damage. Stem rust is much more serious than leaf rust, especially in northern China.

Main diseases of fodder oats in China

Smuts

Both loose smut, caused by *Ustilago avenae*, and covered smut, caused by *Ustilago kolleri*, are seedborne and seed is the only source of inoculum. Loose smut is more prevalent in humid regions and covered smut in drier regions. After seed is sown, mycelia grow into and infect young oat shoots. By heading time, kernels and hulls are completely replaced by chlamydospores, which are released into the air and disseminated by wind to healthy heads before harvest. Smut occurs prevalently in the north and northwest of China and has been one of the most destructive oat diseases. In the 1950s, infection by oat smut reached as much as 46 to 90 percent in some fields in Hebei, Shanxi, Inner Mongolia and Gansu provinces. The annual loss due to smut in China could be 7 to 10 percent. Both smuts may be controlled by seed treatment and the use of resistant cultivars.

Fungicides such as triazole, dithiocarbamate and maneb have proved to be very effective for controlling oat smut. They have no ill effect on seed germination if used correctly. Precautions should be taken against inhaling these fungicides. There is less danger when they are used in liquid or wet forms. Seed treatment five to seven days prior to seeding has better results.

In 1982, 479 naked oats and 611 hulled oats lines were inoculated with smut. There were only one highly resistant and three resistant cultivars in the naked group; in contrast, there were 148 highly resistant and 256 resistant cultivars in the hulled group. Through cross-breeding of naked and hulled oats, a series of naked smut-resistant cultivars were developed, such as Huabei 2, Neiyan 5, Bayan 4, Bayan 5 and Bayan 6.

Despite the use of resistant cultivars and chemical measures to reduce disease levels, smut still occurs in some areas. Comprehensive measures available to prevent smut include seed selection, rogueing out of infected plants after heading and avoiding continuous cropping.

Stem rust

Stem rust attacks the stem in particular, but in severe epidemics it may be found on the leaves and glumes, which results in loss of quality of oat straw for hay or for grazing. The pustules are reddish brown, oblong and usually begin to appear on the plants before heading. In contrast to crown rust, the pustules of stem rust are darker in colour and cause a distinct rupturing of the plant epidermis. The pustules are filled with spores, which are rapidly scattered by the wind to infect nearby plants or those in more distant fields. Air currents carry spores a great distance.

During humid weather, which is very favourable for rust development, the first infections spread rapidly and may result in a destructive rust epidemic. Cool, dry weather hinders the spread of the disease. The red rust stage is followed by the black stage as the crop matures. The black colour is due to the black overwintering spores formed in the same pustules. Black spores which have overwintered on stubble, etc., germinate in the spring and are only able to infect the leaves of the common barberry (*Berberis vulgaris* L.), the alternate host of stem rust. Spores from small cup-like bodies formed on the undersurface of the barberry leaves are, in turn, able, to infect susceptible oat plants in the early summer. Stem rust occurs greatly in Inner Mongolia in mid- and late July, when the temperature is around 18 to 21°C. In the southwest of China, such as Yunnan, Guizhou and Sichuan provinces, where autumn-sown oats are grown, very little stem rust is found because when stem rust occurs in the north and northwest, autumn-sown oats have been harvested.

The best way to control stem rust is the use of resistant cultivars, such as Bayan 4, Bayan 5, Neiyan 5 and Yongqing 473. In the northwestern region, where barberry is absent, early planting may effectively avoid and reduce infection from urediniospores blowing from other areas. Triazole-type foliar fungicide to control stem rust is available, but may not be economic. If rain occurs within one hour of application, reapplication may be necessary. Avoid spraying in a dead calm or when winds are gusty.

Crown rust

Found in the 1940s in the southwest of China, crown rust (*Puccinia coronata*) has proved to be worse than stem rust. It usually occurs in late March in the plains region, and infection time becomes later with increasing altitude. Crown rust at first forms small bright orange-yellow pustules, which are found almost entirely on the leaf blades and sheaths.

Later-formed pustules are larger. They are long and irregular in shape. There is no conspicuous rupturing of the plant surface at the border of the pustules, in contrast with stem rust. The pustules of the black spore stage are covered by a thin layer of epidermis and hence are less noticeable than those of stem rust. The over-wintering black spores germinate in spring and cause elevated orange-yellow lesions to form on the leaves of the buckthorn (*Rhamnus* spp.), the alternate host of crown rust. The spores are then carried by the wind from buckthorn to infect young oat plants. Secondary infection, from earlier infected oats, is responsible for the main losses. Crown rust may lower both yield and quality of grain or hay, and bad infection can cause lodging in some fields. The effective way to control this disease is developing resistant cultivars. Proper application of triazole-type foliar fungicide can control oat crown rust.

Barley Yellow Dwarf Virus (BYDV)

BYDV, also called oat red leaf, was first recorded in 1951. In past decades, BYDV was occasionally prevalent in some areas, and caused great yield losses in some years. It is an aphid-borne disease caused by a group of virus strains that can infect most genera and species of grasses. Aphid transmission is the only mechanism of disease spread. There are two common aphids, *Schizaphis graminum* Rondani and *Macrosiphum avenae* Fab., known to be vectors in China. Virus strains are numerous and some are specialized in their relationships with the vectors. Virus strains that overwinter on winter cereals or perennial grasses constitute almost all of the virus inocula responsible for yellow dwarf outbreaks on oats in China. In the north, epidemics are caused by the first migrations of alate aphids in mid- or late May. Observations indicate that infestation caused by several aphid species were much more serious than by one aphid species. Occasionally, epidemics develop gradually within a field from an initially low aphid infestation, with wingless aphids as the main vector. Symptoms of the disease take two or more weeks to become visible. The most effective control of yellow dwarf is to grow tolerant cultivars. The Chinese Academy of Agricultural Science evaluated numerous hulled and naked oat landraces and found that Yong 492, Baxuan 1, Baxuan 2, Jinyan 8 and 738-66-1 were resistant to BYDV. In Shanxi province, early seeding may increase damage to some extent because the crop can suffer twice from infection challenge (Guo *et al*., 1998). Insecticides to kill the vector aphids are available as a means of controlling BYDV, but are not economic.

OTHER PROBLEMS

Lodging

Lodging is often responsible for great losses in oats; this is obvious in the areas where moisture is abundant, where storms commonly occur or where the soil is rich in nitrogen or deficient in minerals. Lodging usually lowers the yield and quality of grain and straw, and makes harvesting difficult.

The damage caused by lodging depends largely on the stage of growth at which the crop goes down. When a green crop lodges, the plants usually bend over at ground level. During heavy storms, considerable pressure is exerted on the stems and particularly at the point of anchorage to the ground. Cultivars that are not too

tall and have thick lower stems, combined with large and branching anchor roots giving maximum support, are the ones that do not lodge readily. Lodging prior to maturity is commonest in crops on very fertile soils having higher levels of nitrogen. Where moisture is the limiting factor in crop production, the effect of previous crops on lodging is less noticeable. It is well known that phosphate fertilizers are important for good plant development and tend to hasten maturity, thereby lessening the damage from lodging caused by late summer storms.

High seed rates increase lodging because the plants are more spindly as a result of competition (Chen, Li and Shi, 2000). Early sowing has tended to produce crops with stronger straw. This may be the result of a more suitable growing season, which leads to better plant development. Early-sown crops also have a greater chance of escaping heavy storms.

Another type of lodging may occur as the grain approaches maturity, when the straw gradually loses its flexibility and become brittle. At this stage, breaks occur higher up the stem. Early in 1982, the Chinese Academy of Agricultural Science evaluated parts of naked and hulled oats, both cultivated in China and introduced, at filling stage, milk stage and dough stage. Thirty-six cultivars did not lodge at milk stage, and most of the lodging cultivars were early naked oats from Shanxi, with a plant height exceeding 100 cm. Only two naked oat cultivars kept standing at the dough stage: Yong 492, a naked oat derived from an introduction from France; and "Iron stem and large grain", a cultivar developed in Hebei province. The Inner Mongolian Academy of Agricultural Science evaluated hulled oats and found cultivars from Qinghai, Xinjiang and Gansu provinces, together with some introduced from Australia, Canada, Denmark, France, Japan and USA, that were resistant to lodging. Lodging resistance was found to be associated with internal stem structure and size, and with anchor root development. Such finding can be directly applied to the development of cultivars that will stand up under conditions of high fertility and abundant moisture, and at the same time meet the requirements for high yield and good quality.

Drought

For maximum development, oats require plenty of moisture throughout the growing period. Some areas of China suffer from too little moisture and a high degree of evaporation, which tend to increase the hazards of growing this crop. In these areas, drought may occur at various times during the growing season, with attendant danger of crop failure. Insufficient moisture in early growth stages tend to produce weakened plants with sparse tillering. The effect of drought in the latter part of the growing season is reduced filling and yield. Early seeding and the use of early-maturing cultivars often enables the crop to escape drought damage during the later stages of growth. In China, efforts are being made to evaluate the drought tolerance of cultivars in different areas, and to incorporate drought resistance from foreign sources and landraces into better oat cultivars (Xin, Dong and Song, 1996).

Frost

Frost damage, in either the spring or autumn, is a hazard for oat production in

TABLE 8.5
Major oat cultivars grown in the period 1960 to 1989 in China

Cultivar	Pedigree	Resources	Type	Characteristics
73-7	T-195 from Canada	Inner Mongolia	Spring naked	Good quality; susceptible to BYDV
Yong 492	Nuprime from France	Inner Mongolia	Spring naked	Good quality; high tillering capacity; lodging resistant
Huabei 2	8np 1988 from USSR	Inner Mongolia	Spring naked	Good quality; medium resistance to BYDV
Jianzhaung	From Belgium	Inner Mongolia	Spring hulled	Lodging and disease resistant
Neiyan 5	Yong 380/Huabei 2	Inner Mongolia	Spring naked	Lodging and disease resistant
Mengyan 7413	Jianzhuang/Yong 492	Inner Mongolia	Spring naked	Lodging and BYDV resistant
Jiza 2	Triumph/Sweet Oat	Hebei	Spring naked	Drought, lodging and disease resistant
8axuan 3	Introduced from Hungary	Hebei	Spring naked	Lodging and shattering resistant
Jizhangyan 1	–	Hebei	Spring naked	Lodging and drought resistant; susceptible to false smut
Pin 1	Yong 492/Yong 118	Hebei	Spring naked	Lodging resistant
Jinyan 5	Hubei 2/Yong 99	Shanxi	Spring naked	Drought resistant
Neiyou 2	8axuan 3/Jianzhang	Inner Mongolia	Spring naked	High yielding
Neiyou 1	Huabei 2/Milford	Inner Mongolia	Spring naked	Lodging resistant; susceptible to rust
Jinyan 1	Huabei 2/Huabei 1	Shanxi	Spring naked	Large kernel; high tillering ability
Jinyan 2	Landrace	Shanxi	Spring naked	Drought resistant; lodging susceptible
Jinyan 3	Huabei 1/Sanfensan	Shanxi	Spring naked	Drought resistant; wide adaptability
Jinyan 4	Huabei 2/Sanfensan	Shanxi	Spring naked	Multiple floret; large kernel; drought resistant
Yanhong 10	Huabei 2/Sanfensan	Shanxi	Spring naked	Multiple floret; large kernel; drought and lodging resistant

some areas. This is particularly important where the frost-free growing period is short, as in Qinghai. Usually oats are more able to make a better recovery from spring frost injury than are other cereals. Early autumn frost damage is particularly detrimental when the crop is intended for grain production. When oats are grown for grain, early maturing cultivars are favourable. If oats cannot be harvested for grain because of a limiting thermal regime, vegetative fast-growing cultivars should be used, such as fodder oat cultivar Qinghai 444 (Shi *et al.*, 1999).

OAT BREEDING AND GERMPLASM ENHANCEMENT

History of key oat cultivars

Although naked oats originated in China, no research institute engaged in oat breeding until 1949. Chinese oat breeding began in the 1950s, when some research institutes in oat growing areas in the north started to collect and evaluate local landraces. In the 1960s, the situation improved and the Chinese Academy of Agricultural Science organized specific agencies to collect, conserve and evaluate domestic and foreign hulled and naked oat germplasm.

TABLE 8.6
Major oat cultivars grown in the 1990s in China

Cultivar	Pedigree	Source	Type	Characteristics
Bayan 4	Bayan 3/Denmark 146	Qinghai	Spring hulled	Drought, cold and lodging resistant
Bayan 5	Bayan 3/Denmark 146	Qinghai	Spring hulled	Drought, cold and lodging resistant
Bayan 6	Bayan 3/Denmark 146	Qinghai	Spring hulled	Drought, cold and lodging resistant
Qinghai 444	-	Qinghai	Spring hulled	High-yielding, good quality, drought and cold resistant
Xuan 1B	-	Qinghai	Spring hulled	Drought and cold resistant
Qingyongjiu 473	-	Qinghai	Spring hulled	High-yielding, good quality, drought and cold resistant
Qingyongjiu 233	-	Qinghai	Spring hulled	High-yielding, good quality, drought and cold resistant
Qingyongjiu 001	-	Qinghai	Spring hulled	High-yielding, good quality, drought and cold resistant
Mengyanyou 5	5-1-3/Magna	Inner Mongolia	Spring naked	High protein, large kernel
Xiyan 3	A11-2/9-14-1	Inner Mongolia	Spring naked	Early maturity, drought resistant and good quality
Bayou 1	Jizhangyou 4/8061-4-1	Hebei	Spring naked	High protein and fat, lodging resistant
Bayou 2	84113-7/Jizhangyou 4	Hebei	Spring naked	Drought resistant and wide adaptability
Caoyou 1	Jizhangyan 1/Baxuan 3	Inner Mongolia	Spring naked	High hay yield and good quality
Dingyou 1	955/Yong 492	Gansu	Spring naked	Good quality, drought and lodging resistant
Huazao 2	Jizhangyou 2/Mapiya	Hebei	Spring naked	Extra-early maturity; lodging and false smut resistant
Huazhong 21	-	Hebei	Spring naked	Drought and lodging resistant
Huawan 6	Denmark 731/ Jizhangyou 6	Hebei	Spring naked	Drought, lodging and BYDV resistant
Pin 2	73-1/Yong 492	Hebei	Spring naked	Extra-early maturity; lodging resistant
Jizhangyou 4	Yong 118/Hubei 2	Hebei	Spring naked	High-yielding, drought and BYDV resistant
Jizhangyou 5	347/Yong 118	Hebei	Spring naked	Lodging resistant; susceptible to BYDV and false smut

Since the early 1970s, oat breeding institutions have focused on hybridization between naked and hulled oats, aiming to overcome the weaknesses of Chinese naked oats, such as weak stem and low grain weight. By 1989, the oat breeding programmes in provincial institutes had released a series of cultivars, including Sanfensan, Huabei 1, Huabei 2, Tongxihao, Yanhonghao, Jinyanhao, Baxuanhao, Wuyanhao, 73-7, Yong 492 and Yong 578, all of which were naked oats (Yang and Sun, 1989) (Table 8.5).

Between 1990 and the present, new oat cultivars have been developed more rapidly than before. With strong support from the central government and cooperation between institutions, a number of new oat cultivars with high yield potential and multiresistance were developed and quickly released in the corresponding oat cultivation areas (Table 8.6).

Current breeding and research

Oat genetic resources

A large collection of Chinese and foreign germplasm, with almost 3000 accessions,

TABLE 8.7
Accessions of oat germplasm in China as of 1997

	Domestic accessions			Foreign accessions	
Province	Naked oats	Hulled oats	Country	Naked oats	Hulled oats
Shanxi	953		Denmark		502
Inner Mongolia	458	64	Canada	36	67
Hebei	81		USSR		84
Qinghai		95	USA		63
Xinjiang		62	Hungary		52
Others	171	78	Others		201
Total	1663	309	Total	36	969

SOURCE: Ma and Tian, 1998

recently set up by the Chinese Academy of Agricultural Science and Hebei Academy of Agricultural Science (Ma and Tian, 1998), is stored in the Germplasm Institute of Chinese Academy of Agricultural Science, Inner Mongolian Academy of Agricultural Science, and other institutes. This collection included 1 972 Chinese and 1 005 foreign accessions. Table 8.7 indicates the number, type and sources of this collection. Accessions have been further characterized for agronomic and quality characteristics. Seed stocks for breeding are furnished upon request. Enhanced germplasm is added to the stocks for future use. Most of the germplasm has been released or registered.

Introduction and reselection

Early oat breeders assembled cultivars from throughout the world and grew them in field tests to identify those that were best adapted. Fu, Liu and Liu (1999) reviewed the application of introduced oat cultivars to new naked oat cultivar breeding. Two widely grown cultivars introduced into China were cv BnP 1988 from USSR in 1960, and cv. Nuprime from France in 1971. Many of the introductions were mixtures of homozygous genotypes, so oat breeders practiced "pure line" or "individual plant selection" to isolate the highest-yielding and best-adapted genotypes from the mixtures. Pure line selection is essentially the increasing and testing of the progeny from selected single plants. This method is still a basic technique for oat improvement. However, various methods are used to increase variability prior to selection.

Hybridization and wide crosses

Oat hybridization in China began in the early 1970s. To date, most oat cultivars have been developed through hybridization. Modern oat breeders rely almost entirely on hybridization, followed by selection, for the development of improved cultivars. The high-yielding naked oat Neiyan 5 is a successful example of a cultivar obtained through the crossing of hulled oat cv. Yong 380 and naked oat cv. Huabei 2 (Sun, Chang and Li, 1991). The technique of selection after hybridization between hexaploid naked and hexaploid hulled oats was reported by Gu, Li and Wang (1997). The results indicated that hybrid progeny between hulled and naked *Avena sativa* showed mixed inheritance. Selection focused on parental selection, pollination method, continuous single-plant grain selection, and biomass and harvest index.

Some researchers tried to use wide crosses between hexaploid naked oat and the wild tetraploid species *Avena magna* to increase genetic variability in the breeding material. Primary attention was paid to finding new sources of high feeding quality and resistance to diseases, pests and abiotic stresses. Fu, Li and Sun (1995) successfully incorporated high-protein genes from *Avena magna* into hexaploid naked oats. The protein content of several progenies reached 18–20 percent. Observations on fertilization and early embryo development in the intergeneric cross indicated that pollen germination of *Avena sativa* appeared to be normal on the stigma of *Avena magna* and the pollen tubes grew into the style and entered the embryo sacs (Zhao, Liu and Yang, 2001).

Tissue culture

In recent decades, there have been several reports of plant regeneration and potentially useful genetic variation derived from tissue culture of oats, and the use of such variation in a breeding programme has been reported (Fan and Cui, 1995). The use of tissue culture variation deserves serious consideration by oat breeders and hopefully such variation can be used to develop improved cultivars of oats.

Culture from somatic tissues

Li *et al.* (1991) studied the relationship between endogenous hormones of immature inflorescences of naked oats and somatic embryogenesis. They found that, along with the development and differentiation of the shoot tip, the requirement for indole acetic acid (IAA) for its growth and differentiation increased. In the undifferentiated and embryogenic calli the ratios of IAA to CTK were 1.8 : 1 and 5.1 : 1, respectively. The optimization of concentration of 2,4-D could increase callus induction. Fan and Cui (1996a) reported a technique of callus induction and plant regeneration with young panicles of naked oat on N_6 medium. The optimal length of the material was 1–2 cm, which could increase the frequency of induction (74.7 percent). Cui and Fan (1996; 1998) also reported the successful culture of embryogenetic calli and plant regeneration from mature embryo on N_6 medium. A suspension system was also established. Yang *et al.* (1998) reported obtaining hybridized plants from the cross of tetraploid *Avena magna* and hexaploid naked oats, using immature embryos on MS medium.

Culture from gametophytic tissues

Sun, Lu and Söndahl (1991) reported the production of haploid plants through anther culture in naked oat using MS callus medium. They found that MS medium with 4 percent sucrose, 1 percent activated charcoal and no exogenous auxin supplement gave the highest initiation frequencies (14.7 percent) of anther callus among media tested. The cell suspension cultures were established from pollen friable calli in liquid medium. The suspension cells were cytologically stable over one year. The successful application of this technique in oat production led to the development of Huazao 2, Huazhong 21 and Huawan 6, which were the first cultivars produced by this technique in China. They are all naked and have been released in north China (Yang, 2001).

Hybrid oat development

Since its discovery in China in 1994, CA [China *Avena sativa*] male sterility has

been increasingly used in oat breeding programmes. Fan and Cui (1996b) reported that this male sterility was found in a hulled parent. Cui *et al.* (1999) looked at the genetic identification of this male-sterile oat and found that the sterility was steady and that it belongs to the pollenless type, with 100 percent sterility. Fertility of F_1 hybrids was restored in six combinations, and, when self-crossing, ¾ fertile plants and ¼ sterile plants segregated in the F_2. When F_1 progenies were crossed with the sterile plant, a 1 : 1 sterile : fertile segregation was obtained. Based on these observations, the sterility is controlled by recessive nuclear genes. As it was the first oat sterility found in China, it was named the "CA male-sterile oat".

THEMES AND SUBJECTS REQUIRING RESEARCH OR EXTENSION

Oats are chiefly a crop in northern areas of China. These areas have the cool, moist climate to which oats are best adapted. In recent years, the hulled oat area for fodder increased sharply compared with naked oats for grain. One of the explanations is that hulled oat introductions played or are still playing a very important role in these pastoral areas (Shi *et al.*, 1999). In Qinghai, cultivation of hulled oats in *Quan Wozi* (the winter pen on a family farm) has had an especially great effect on the development of husbandry as it can provide high quality feed in winter and in the early spring. However, the lack of methods to build highly sown forage is still a bottleneck limiting the potential of hulled oats. In these areas, oat cultivar introduction and evaluation are a crucial means of increasing oat production potential (Zhang, *et al.*, 2002). More and more personnel and agencies are providing oat germplasm to areas of China as a valuable input to accelerate oat extension and cultivar improvement. A Canadian oat breeder, Dr Burrows, visited the Baicheng area of Jilin province to help guide the oat production programme and donated 260 germplasm lines and more than 160 hybrid combinations (not included in Table 8.7). His generosity and contribution to the agricultural development of China is truly appreciated (Ren *et al.*, 2002; Chen, 2002).

However, cultivar introduction is not the ultimate way to solve the problems appearing in oat production, so some areas in Tibet Autonomous Region and Qinghai province have set up seed production bases (Jin, 2000; Chen *et al.*, 2002). For instance, the biggest oat seed multiplication base, established in Huangzhong county of Qinghai province, sponsored by the Agricultural Ministry of China, has been in use since 2003 and can produce more than 5 000 t of seed annually. Unfortunately, for a long time, most effort was put into the improvement of naked rather than fodder oats, so the small number of fodder oat cultivars is another limiting factor in the development of fodder production in pastoral areas. In the longer term, much more attention should be paid to fodder oat breeding, with a target of early maturity, high green feed or hay yield, cold tolerance and high protein in grain.

Plant breeding alone will not be enough. A multidisciplinary and integrated approach is needed, including associated livestock improvement, and mechanization of seeding, harvesting, grain cleaning and storage, hay storage and silage ensiling. Agencies are also needed to facilitate effective cooperation with inter-

national agencies to bring Chinese fodder oat production up to world standards.

PERSPECTIVES

In China, continuous population growth and loss of farming land encourages protection of the living environment and promotion of living quality. Unfortunately, in past decades, overproduction of cereals and overstocking of livestock have resulted in environmental deterioration and degradation of arable land and grasslands. The agricultural production structure has to be adjusted to meet the requirement for healthy economic growth in rural areas, especially in cooler regions of China, where maize and soybean cannot be grown successfully because of low temperatures and where oats could be an ideal option in the production of forage and could provide livestock with ample feed in the winter and early spring. According to the Tenth Five-Year Plan (2000–2005), grassland development and feeding domestic animals with straw have received more attention by the government, and livestock development has been placed in a very important position to face competition from all around the world after entry to the WTO. In these five years, 1.3 million hectares of grassland will be established, 20 forage breeder's seed bases and 136 forage seed multiplication bases will be constructed. Oats, as a most valuable fodder, will be further recognized and used widely in most grazing areas. For instance, 9 000–13 000 t of fodder oat seeds will be needed in Qinghai and nearby regions of other provinces, but only 31 percent of this requirement can be met through the current seed market (Zhou, 2003). So in the near future, fodder oats should develop rapidly because this crop can bring good returns to farmers and ranchers.

CONCLUSION

Oats have been grown in China for at least 2100 years and were always a staple food. Its importance lessened after 1974 because maize, wheat and soybean production expanded and supplanted it. However, the yield per unit area has increased rapidly as a result of successful oat breeding programmes in areas where oats are grown widely. The main areas for oat production are in the northwest, north and northeast of China, with the cool, moist climates to which oats are best adapted. Oats are adapted to a wide range of soil types, but temperature and moisture conditions are the limiting factors in production. In recent years, the importance of oats as fodder – pasture, hay, silage and feed grain – has been recognized more by farmers and government because of its high feeding value and environmental conservation function. Naked oats are considered a cash crop in rotations and will become a grain of commerce with the development of food processing industry. The potential is so high as to permit this crop to play a very important role in the development of the agricultural economy of China.

Chapter IX
Fodder oats in Japan

Masaaki Katsura

SUMMARY

Oats for fodder were grown on over 8 000 ha in Japan in 2000. Oats are now grown for fodder rather than grain, and the main cultivation area of fodder oats has shifted from Hokkaido to Kyushu. Oats are recognized as an important fodder crop for early winter and spring. The system adopted in the warm region of Japan has oats sown in late summer and harvested for silage or hay in December or later. Seven forage-type cultivars have been released in the past twenty years, and the breeding programme now aims to develop varieties for summer sowing.

INTRODUCTION

Oats are grown as a forage crop all over Japan, from Hokkaido to Kyushu, and used as grain, green fodder, silage and green manure. The cultivation of oats in Japan began in 1872, when oat seeds were introduced from the USA by hand of *Kaitakushi*, the Colonial Bureau in Hokkaido. As oats are suited to cool temperatures and adequate moisture, they are well adapted to the climate of Hokkaido, but not much grown because of poor demand for oats for feed. Cultivated species in Japan are *Avena sativa* L. and *A. strigosa* Schreb. The sown area was about 973 ha in 1894. After that, the livestock industry expanded and keeping of horses and cows increased. Oats were also excellent feed for riding horses, so demand for oats increased gradually and the area expanded every year, reaching 144 300 ha in 1942. After the Second World War, the area fell as there was little demand for horse feed. The increase in sown pasture in Hokkaido and imported concentrates accelerated the decline in cultivation of oats for grain. The area of oats sown for grain in 2000 was 844 ha.

Oats for fodder and silage were rare before the Second World War. In the 1960s, great importance was attached to growing forages in association with the promotion of livestock raising, and many types of forage were grown all over Japan. Oats for fodder and silage attracted attention because of their rapid growth, high yield, palatability and excellent composition, and were grown as winter forage in warmer regions, mostly in Kyushu. The area of oats for fodder and silage reached 31 400 ha in 1969, but has since declined as the area sown to Italian ryegrass (*Lolium multiflorum* Lam.) has expanded. The area of oats for green fodder and silage in 2000 was 8 060 ha. The transition and distribution of fodder oats in Japan are shown in Figure 9.1 and Table 9.1. Locations and their climatic conditions for some areas where oats have been much cultivated are shown in Figures 9.2 and 9.3.

Oats for grain

The general cultivation pattern in Hokkaido is that oats are sown in late April to May and harvested in August (Tannno *et al.*, 1982, 1983; Yoshihira

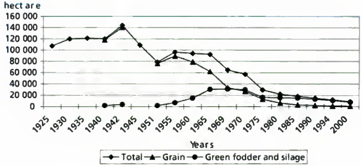


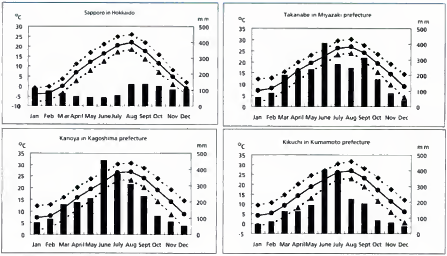
Figure 9.1

Changes in fodder oat area in Japan

SOURCE Statistics on Crops, and Statistics on Cultivated Land and Planted Area, Statistics Department, Ministry of Agriculture, Forestry and Fisheries of Japan.

Figure 9.2

Locations where oats were formerly widely cultivated in Japan



Figures 9.3a, b, c and d

Climatic conditions for four areas in Japan where oats are cultivated.
The left axis shows temperature (°C) and the right axis shows precipitation (mm).
The black circles, diamonds and triangles are monthly average temperature, monthly maximum temperature and monthly minimum temperature, respectively. The bar graph shows monthly total precipitation.

Source: Japan Meteorological Agency

TABLE 9.1
Distribution and area (ha) of cultivation of grain and fodder oats in Japan for three years

District	1942		1969		2000	
	Grain	Fodder and silage	Grain	Fodder and silage	Grain	Fodder and silage
Hokkaido	137 186	1 422	27 000	3 930	719	88
Kumamoto	212	541	200	2 610	–	252
Miyazaki	3 467	435	2 680	5 560	5	1 200
Kagoshima	1 681	772	3 110	7 350	104	3 270
Total	144 265	3 762	33 700	31 400	844	8 060

Source: Statistics on Crops, and Statistics on Cultivated Land and Planted Area, Statistics Department, Ministry of Agriculture, Forestry and Fisheries of Japan.

et al., 1994). The yield per ha is about two tonnes. Characteristics required of cultivars for grain are excellent disease resistance and resistance to lodging. Such cultivars have been introduced from abroad and developed in Hokkaido. In Kyushu, in general, oats are sown in October to November and harvested in the following spring.

Cultivation for green fodder and silage

There are three cultivation patterns for green fodder and silage in Japan, but, in warm regions, oats sown in late summer and harvested as silage or hay in December or later is now the main cultivation system.

Spring-sown oats

In Hokkaido summer oats are grown as for grain and harvest is after mid-July (Iwasaki *et al.*, 1978; Tobino *et al.*, 1976). This system is not so common in the southwest warm region where cultivars with a spring habit are sown in February or March, and harvested as whole-crop silage in May or June. To harvest as hay after the rainy season, the sowing date can be modified.

Autumn-sown oats

Oats are sown in autumn in south-western Japan and harvested in spring (Miaki and Nose 1967; Taji, 1966; Taji *et al.*, 1977; Ueda and Kakihara, 1988). Some mow oats twice, cutting luxuriant oats in early spring as green feed and next harvest regrowth for green feed, silage, hay or allowing growth to proceed for grain production (Nishimura *et al.*, 1955, 1960b; Nishimura and Saito, 1958, 1960). In Kyushu, early maturing cultivars are sown from late October to early November; heading starts in April and they reach milky to dough stage in May, which is the time for harvest as silage (Hosoya *et al.*, 1988; Nishida and Nakano, 1979). Cultivars suited to autumn sowing vary from very early to medium or late maturing ones. Farmers can select a suitable variety according to their production systems.

Summer-sown oats

This topic was reviewed in Katsura (1999).

The main forages in Japan are summer crops such as maize and sorghum, which are sown in spring and harvested in summer and autumn (Table 9.2). Farmers try to get high yield with high nutritive value. Some farmers try to grow maize twice in a year; as the interval between the first harvest and second seeding is very short, farmers are very busy. In the warm region, maize tends to be sown early to avoid damage by typhoons in late summer, while rice is often transplanted in early spring and also harvested in summer. Therefore, crops following maize or rice are necessary for efficient utilization of fields where arable land is scarce. Oats are an important crop for producing feed in early winter and next spring, along with Italian ryegrass. In the case of summer-sown oats, harvested in early winter, farmers have enough time to prepare for sowing the following crops. To save labour and avoid risk, summer-sown oats are an important alternative. In addition, the weather from autumn to early winter is mild in southwest Japan, particularly in southern Kyushu, i.e. Miyazaki and Kagoshima (Figure 9.2). Enough rain and warmth are easily assured in autumn in these regions. Therefore, this cultivation type is considered to be preferable to make the best use of the climatic conditions.

Summer sowing is not favourable for oats, which is a long-day plant. High temperatures persist until mid-September, which corresponds to the germination stage. Daylength shifts from long to short and temperature from high to low (Figures 9.3a–d). These conditions influence panicle emergence and subsequent growth. Consequently, it is important for farmers to select a variety suitable for summer growing. Oats sown in summer are generally harvested as silage (Ohta *et al.*, 1995) (Figure 9.4), but some farmers harvest it as hay for producing calves; the crop is frosted in December to January to reduce moisture. Small-scale farmers

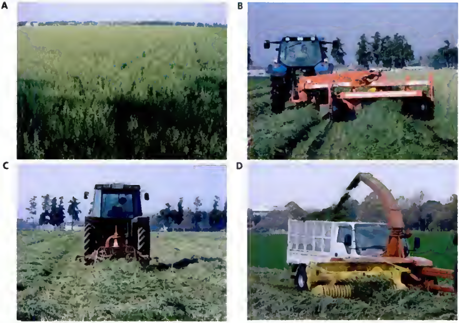


Figure 9.4
The harvest of oats as silage for dairy cattle in summer-sown cultivation. A. Japanese cv. Haeibuki bred for summer cultivation. B. Oats are cut by a mower or a mower conditioner. C. They are turned by tedder and raked once or twice daily for a few days to reduce moisture to 60–70 percent. D. They are chopped finely and transferred for storage in a bunker silo

producing calves sometimes use local oat varieties, which they maintain (Figure 9.5) (Harada *et al.*, 2002; Hayashi and Yawata, 1956; Taji and Akiyoshi, 1966). These are usually grown in small fields and mown in small quantities daily and fed with rice straw. Oat straw is also used as feed (Figure 9.5).

Although the above cropping pattern is pure-crop oats, mixed crops with legumes such as vetch had been used for autumn-sown crops (Hiraishi *et al.*, 1954; Nishimura *et al.*, 1953, 1955b, 1960a, c, d). Now mixed sowing of oats with Italian ryegrass is often used (Kakihara and Fukuda, 1990). They are sown in September or October and harvested twice in winter when the ratio of oats is high, and in the following spring, when only the Italian ryegrass survives. Because of their excellent early growth, oats are often used as a nurse crop or companion crop (Iwasaki *et al.*, 1978; Tabata *et al.*, 1992).

Breeding fodder oats

Oat breeding began in the Meiji era, in the late nineteenth century, for grain in Hokkaido. The objectives were to increase grain yield with early heading and to strengthen lodging resistance, cold resistance and disease resistance. Breeding

Figure 9.5
Use of oats derived from seeds being maintained by farmers.
A. Farmers mow oats in small lots daily. B. After threshing, the oat straw is fed to beef cattle. C. Seed being maintained by a farmer, from material inherited from his parents.

oats for grain stopped in 1994 because of their decreasing cultivation, as mentioned earlier. Breeding oats for forage began in Hokkaido as the use of oats changed from grain to forage. Since the main area of forage oats has shifted from Hokkaido to Kyushu, breeding of oats for forage started in 1988 in Kyushu.

Oat cultivation is now mostly for green fodder and silage; this is expected to continue. The breeding of forage oats for summer-sown cultivation has been intensive for the past twenty years. The cultivars for summer-sown cultivation have been primarily introduced from the United States of America and from Australia. As they were not bred to grow in the summer in Japan, it has been necessary to develop some suitable cultivars locally. The focus has been on early heading in autumn, resistance to crown rust (*Puccinia coronata* Corda) and lodging resistance. Those characteristics are very important to obtain oats of high quality. As a result of this work, cultivars Haeibuki and Tachiibuki have been released, which have superior qualities under Japanese condition, especially in lodging resistance.

Oat cultivars developed in Japan since 1980 are listed below.

Akiyutaka is the first variety for forage and green manure developed at the Hokkaido National Agricultural

TABLE 9.2
Sowing and harvest seasons of major fodders in Japan.

	Summer oats	Autumn oats	Italian Ryegrass	1st Maize	2nd Maize	Sorghum
August				Harvest	Sowing	Harvest 20 t DM ha^{-1}
September	Sowing at 60–80 kg ha^{-1}				Growing	
October		Sowing at 60–80 kg ha^{-1}	Sowing at 20–30 kg ha^{-1}			
November	Growing				Harvest 7 t DM ha^{-1}	
December			Growing			
January	Harvest 7 t DM ha^{-1}					
February		Growing				
March						
April			Harvest 11 t DM ha^{-1}	Sowing at 2 kg ha^{-1}		
May		Harvest 12 t DM ha^{-1}		Growing		Sowing at 2–3 kg ha^{-1}
June						Growing
July				Harvest 18 t DM ha^{-1}	Sowing at 2 kg ha^{-1}	Harvest

Experiment Station, in 1980 (Tabata and Kumagai, 1985). It is well adapted for autumn-sown fodder in southern Japan.

Hidaka, bred at the Hokkaido National Agricultural Experiment Station in 1990, is a highly lodging-resistant and high-yielding variety for grain (Tabata *et al.*, 1994). It is adapted to all Hokkaido.

Akiwase, developed at the Hokkaido National Agricultural Experiment Station in 1989, is extremely early maturing, suitable for summer sowing, with good lodging resistance (Tabata *et al.*, 1992).

Super Hayate Hayabusa, developed by the Snow Brand Seed Co. in 1992, is an extremely early maturing and high-yielding variety for summer and autumn sowing; not suitable for grain production.

Haeibuki, bred for silage or green fodder at Kyushu National Agricultural Experiment Station in 1996 (Ueyama *et al.*, 2001) is an extremely early maturing cultivar suitable for summer sowing. Summer-sown Haeibuki heads before Akiwase.

Kanmuri, developed at the Hokkaido National Agricultural Experiment Station in 1995, is highly resistant to crown rust in Yamaguchi, Miyazaki and Okinawa prefectures. It is recommended for areas where crown rust is prevalent in southern Japan, such as Chugoku, Kyushu and Okinawa districts, mainly for autumn sowing (Takada *et al.*, 1999).

Tachiibuki, bred for silage or green fodder at Kyushu National Agricultural Experiment Station in 2000, is an extremely early cultivar suitable for summer sowing. Its lodging resistance is much greater than Super Hayate Hayabusa and Haeibuki in summer- and autumn-sown cultivation.

PROSPECTS

Breeding oats for grain in Hokkaido stopped in 1994 and the area of oats for grain remains small. Grain production, except for very early or early maturing cultivars, is difficult in Kyushu because of the rainy season in June and July, when medium or late maturing oats mature. Growing oats for forage, both summer-sown and autumn-sown, in the warm region does not compete with growing summer crops such as maize and paddy rice. It is easy to rotate summer crops and oats in fields. There is much arable land where farmers grow nothing after harvesting the summer crops, potentially allowing oats to be grown in the break.

In Japan, self-sufficiency in food was 40 percent on a calorie basis in 2001. Raising this figure has become an important element in Japanese agricultural policy. It is necessary to improve the self-sufficiency in feed because Japan imports most feed and self-sufficiency in feed was only 25 percent in 2001. Large quantities of oat grain and hay are imported from Australia, the USA, Canada, etc. The quantity of imported feed shows no tendency to reduce, and there are problems in management of livestock because farmers are dependent on overseas supplies, the organic matter cycle is unbalanced, pollution builds up, and so on.

Although the area of oats for feed has been decreasing in Japan, the demand for feed oats is very high. Oats are an important forage for increasing feed auto-sufficiency. Cultivars with excellent resistance to lodging and disease have been developed recently, with another due to be released soon. They are very important for production of high quality forage, and such cultivars will contribute to improved self-sufficiency in feed in Japan.

Chapter X
Fodder oats in New Zealand and Australia – history, production and potential

Keith Armstrong, John de Ruiter and Howard Bezar

SUMMARY

Oats are a multi-purpose crop in New Zealand and Australia, for grain, feed, fodder and straw. Oat forages comprise the largest component of the supplementary cereal forage markets. Dual-purpose cultivars are widely used in Australia for grazing. New Zealand has moved toward cultivars bred for forage. Oat fodder production is mainly in the southern agricultural regions of both countries, but grazing areas are expanding in subtropical Queensland and the temperate North Island of New Zealand, where Crown rust infestation is still the major limiting factor. Oats are mainly used on-farm in New Zealand, but an increasing proportion is traded on the cereal green feed market. In Australia, there has been a rapid increase in the export of cereal hay, around 75 percent of which is derived from oats. In New Zealand, traditional breeding and selection is being used to generate new fodder cultivars with desirable characters, such as disease resistance, improved cool season growth and improved quality; animal response testing is ongoing. Most plant breeding programmes in Australia develop cultivars suitable for both grain and fodder uses, although, in Queensland, private and public oat breeding focuses almost entirely on oat forage cultivars for grazing. Oat production is likely to concentrate where oats have a natural advantage over other crops, notably in waterlogged environments, and where tolerance of frost and acid soils is needed. In Australia and New Zealand, there is an aging population of plant breeders and little succession planning by organizations. It is essential that investment be made in training new plant breeders, ensuring that new entrants have the necessary breadth of knowledge to succeed, and the resources with which to work.

INTRODUCTION

Oats are a multipurpose crop in New Zealand and Australia, and are used for grain for milling, feed grains, grazing forages (or fodder), straw for bedding, hay, haylage, silage, chaff and green manure. Oat forages comprise the largest component of the supplementary cereal forage markets and play an important role in achieving animal production targets, compensating for high stocking rates, and supplementing forage supply for pastoral production systems.

Dual-purpose oat cultivars are widely used in Australia for grazing. Forage is grazed before stem elongation, allowing the crop to recover and produce grain for harvest. Specialist cultivars for hay production are being developed to meet export quality specifications for Australia's growing oaten hay export trade to Southeast Asia.

In recent years, the New Zealand oat industry has moved away from the use of dual-purpose cultivars toward specialist oat cultivars bred for forage use. This

move is driven by an expanding dairy industry, intensification of livestock grazing lands and improved commodity prices for livestock products.

Oat fodder production occurs mainly in the southern agricultural regions of both New Zealand and Australia, but grazing areas are expanding in subtropical Queensland and the temperate North Island of New Zealand, where crown rust infestation is still the major limiting factor in production.

Hay is the major oaten product in Australia. In 1998/99, 1.35 million tonnes of oaten hay were produced, Western Australia and South Australia being the major producers. Cereal hays are used on-farm as fodder reserves, and traded within the Australian animal feed industry, and for export to Asian markets. In 1999, nearly 300 000 t of oaten hay were exported (Stubbs, 2000).

Oats forages are mainly used for on-farm grazing in New Zealand, but an increasing proportion is traded on the cereal green feed market. Hay and chaff continue to be produced for horses and other livestock, but are less significant as a total percentage of the oaten fodder production system. In New Zealand, oats for grazing are expanding, but total production is very small compared with Australia. There have been no recorded exports of oaten forage products from New Zealand since the early 1900s, when a substantial tonnage of oat chaff was exported to Australia.

Crown rust, *Puccinia coronata*, is the major foliar disease limiting production of forage and oat grain in many of the oat growing regions of the world. Crown rust has the potential to survive between cropping seasons on wild oats or volunteer oat plants, providing a continual supply of inoculum for rust outbreaks each year.

BACKGROUND TO THE AGRICULTURAL SCENE

New Zealand

New Zealand comprises a land area of about 27 million hectares. About two-thirds of the country is inhabited by people, and less than half is in established pasture. New Zealand agriculture relies heavily on grassland pastures, based around ryegrass and white clover, to provide the feed base for its livestock industry. Native tussock grasses predominate in the less productive areas of the "high country".

Production in New Zealand farming systems must satisfy two distinct sets of seasonal requirements. Cattle, including dairy cows, sheep and deer, are the predominant livestock and their feed requirements vary seasonally with the reproductive cycle, lactation and number of stock on the farms. In contrast, perennial pasture and annual crop production follow seasonal regimes that closely parallel weather and climate patterns. Pasture growth varies much more from season to season than do animal feed requirements, creating a demand for on-farm stored supplementary feed, usually in the form of hay and silage. Hay and silage have the disadvantage that their nutritional value is much less than that of the original pasture.

Pasture-derived hay and silage are more predominant on North Island farms than on South Island ones, where more fodder crops for supplementary feed are used. South Island farms have predominantly mixed livestock-grain cropping systems compared with the all-grass farming in the North Island.

The traditional seasonal and management regimes for fodder production and feeding have been challenged in recent years by the increasing demand for higher quality supplementary feeds, an expanding population of dairy cows in both islands, and for fodder supplements to be supplied outside traditional supplementary seasonal feeding timeframes. Forage brassicas and cereals (of which oat and maize crops predominate) are the major arable forage crops used for animal forage supplements in New Zealand.

Australia

Australia comprises a land area of about 770 million hectares, of which 551 million hectares are taken up by farms. About 3 percent of the farm land is used for crops and about 6 percent for sown pasture. The remainder is largely semi-arid grazing land that supports few animals. Improved and unimproved grazing lands, together with hay and other fodder crops, are the basis of the livestock industries. In recent years there has been a rapid increase in the export of cereal hay, of which around 75 percent is derived from oats (Stubbs, 2000).

Total annual fodder production is estimated to be between 4 and 6 million tonnes of hay and up to two million tonnes of silage. Most fodder produced, particularly silage, is fed on the farm in the season following production, or stored as a drought reserve (Stubbs, 2000). The domestic trading market for fodder is mostly pasture and lucerne hay, as well as hay products that are processed as chaff and pellets for the dairy and horse industries, beef feed lots, sheep and beef graziers, stock feed manufacturers and urban markets for use as horticulture and garden mulches. A four-fold increase in cereal hay exports occurred between the 1990 and 1999 seasons, the bulk coming from Western and South Australia. A significant proportion of the export increase was to Japan (Stubbs, 2000).

PRODUCTION AND CROP MANAGEMENT IN NEW ZEALAND

Rise and fall of oat production

According to Claridge (1972), the rise and fall of oat growing in New Zealand is a reflection of changes in the horse population. This may also be true for Australia. As the total cropping area increased towards the end of the nineteenth century, greater quantities of grain and chaff were required to feed horses employed in cultivation and transport. For much of this period, the total area of oats grown in New Zealand exceeded the wheat area. In 1900–01, 178 000 ha of wheat and 182 000 ha of oats were grown in New Zealand (Statistics New Zealand, 1983). In Australia, the 1901 wheat crop accounted for 2 million hectares, and oats 187 000 ha (Pollard, 2001).

From around the late nineteenth century to the beginning of the First World War, considerable quantities of oat grain and chaff were exported to Australia. During this period, grain exports to Australia exceeded 1 million bushels per year and in 1901 exceeded 10 million bushels (Claridge, 1972). No records are available for chaff exports.

The initial declines in the area of oat crops grown in New Zealand and export of oat grain and chaff to Australia were associated with the decline in demand from Australia and the displacement of horses by tractors and other forms of motive power for transport in both coun-

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Figure 10.1
Dairy cows grazing oats in Canterbury, New Zealand

tries. During the 25-year period to the late 1950s, the population of draught horses in New Zealand declined from 175 000 to less than 29 000, resulting in a decline in the demand for chaff (Claridge, 1972).

Oats from the 1950s

Until 1950, most of the oat crop was used for chaff for animal feed. Substantial volumes were exported to Australia. Since then, green feed crops for grazing, of which oats was a major component, have become the major feed use (Wright, 1983). In the 1978–79 season, 30 000 ha of oats were grown in New Zealand for grain harvesting, mostly in the South Island regions of Canterbury, Otago and Southland. Over half of the grain produced was milled in either Gore or Dunedin, with the rest used for seed and animal feed (Wright, 1983).

According to Statistics New Zealand (1983), in the 1981–82 season 26 500 ha of fodder oats were grown in New Zealand, mostly in Canterbury (Figure 10.1). Statistics New Zealand's 1996 and 2002 records for areas sown to grain and arable crops list oats at around 10 000 ha for each of these surveys, suggesting that the oat area may have stabilized.

The statistics give little indication of the multiplicity of fodder uses of oats for green feeding and grain consumed within the farm. An unknown area continues to be sown and used for animal consumption within individual farms, for which

Figure 10.2
Locations of oat production in New Zealand

no production records are available. Approximate areas of oat production are shown in Figure 10.2.

Intensification of land use

In recent years, the intensification of land use, made possible through the expansion of irrigation systems and increased fertilizer use, has created new demands for tradable fodder products that can help achieve animal production targets and supplement forage supply from traditional pastoral production systems. These developments, together with the increased stocking rates on dairy farms, have created an increase in demand for cereals for supplementary grazing and silage.

According to de Ruiter *et al.* (2000), cereals provide a high energy supplement in autumn and winter and can provide a high-fibre feed source from spring sown crops. Oats can contribute to lactating cattle nutrition as a grazed forage, silage or grain. They have the advantage of high yield potential from autumn sowings, and in the North Island complement maize in a double cropping silage system. Their flexibility allows different sowing and harvesting options, depending on current feed supply. Their disadvantages include a lack of cultivars developed specifically for multiple grazing in cooler regions.

Grazing management

Access to cereals for grazing has given farmers greater flexibility to condition dry cattle and to supplement feed for lactating animals. Early autumn sowing of short-season cereal cultivars for grazing by lactating or pregnant cows is common, particularly where high winter growth rates of animals are required. If crops are sown in early March, when soil temperatures are higher, early herbage growth will capitalize on good nitrogen mineralization rates during early crop establishment. Research by de Ruiter *et al.* (2000) showed that a single cut harvest

in early August produced 4.7 t DM ha^{-1} in 148 days from a March sowing in a warm autumn-early winter.

Potentially significant losses can occur through trampling and ground pugging (formation of consolidated mud due to animal traffic), when stock graze in wet conditions. However, according to de Ruiter (2000, unpubl. data), single-graze autumn green feed is a significantly cheaper option than feeding hay. Where mid-winter or spring grazing is required, later maturing oat or long-season cultivars are the best options as they can survive frosts, produce higher dry matter than pasture and provide reasonably high quality feed in winter. Two or even three grazings are possible, depending on regional climates, reducing the wastage from animal treading, and providing more dry matter than a single-graze system.

Crop mixes

There may be potential to improve winter production quality using mixes with grasses or legumes. Little research has been done to validate the potential of mixtures for producing the required dry matter quantity and quality for late winter and early spring grazing (de Ruiter *et al.*, 2002).

Multiple grazing capability

Developing and introducing improved oat cultivars suitable for multiple grazing in cooler climates would enable herbage quality to remain high for the duration of the grazing period, with potential for a silage crop in late November to early December, if grazing ceased in September. The triticale cultivar, Doubletake, recently released jointly by Crop and Food Research (CFR) and Agricom NZ Ltd, provides for the type of multipurpose cereal forage use that farmers have been seeking from cereal oat forages-early grazing, multigrazing and silage production from a single sown crop.

Unlike triticales, oats have the advantage of very fast biomass production from late autumn sowing to first graze, in cooler temperatures. The breeding programme in New Zealand has been developing oat cultivars with greater capability for multigrazing situations, and silage production, whilst maintaining their early biomass production characteristics. The release of cv. Stampede was a step in this direction. It is a green feed oat suitable for one-off hard grazing in winter or multiple light grazing in autumn and winter in the North Island. It has high potential for biomass production, good frost resistance, good crown rust resistance when first released, and quick growth from autumn sowings (de Ruiter, unpubl. data).

Unfortunately, Stampede is now rust susceptible and is being replaced by other high performing cultivars that have more durable resistance to crown rust, equally high potential for biomass production and rapid autumn growth.

Crop management packages

In New Zealand, new forage cereal cultivars will continue to be developed to provide feed for animals at times of seasonal pasture shortages. Management strategies will be updated regularly to optimize nutritive quality and growth characteristics. The widely differing genetic potential of a range of crops, including alternative oat species, have been evaluated for their patterns of productivity and for changes in herbage

Figure 10.3
An autumn-sown cv. Stampede oat crop in the North Island of New Zealand in 2001. Pugging can be a problem for all grazing crops during winter in high rainfall regions

quality in relation to stage of growth and environmental conditions during growth.

New Zealand researchers are also planning animal response experiments to examine the benefits of alternative production methods. Programmes of work are under way on improving the use of forage cereals, maintaining stock health, optimizing dairy production through selection of appropriate germplasm for supplementary feeding and by managing stock to minimize treading damage to soil structure (Figure 10.3).

In addition, research is aimed at optimizing cropping and pasture rotations to enhance the sustainability of production systems. Cultivars produced for specific feed use, such as cut-and-carry, e.g. hay and silage or grazing systems, will be supported by management guidelines and decision support systems. This information will support growers and enhance the adoption of new technology and uptake of new cultivars (Hogg *et al.*, 2002).

New cultivar information packages will include quality and yield characteristics for specific production requirements such as autumn, winter, summer and spring grazing, and hay and silage use. The outcome of these programmes will be more reliable and sustained milk and meat production by overcoming seasonal feed and production supply problems. As a result, dairy cows will maintain the lactation peak for longer in spring and productivity will be enhanced in summer. Factors that influence the suitability of oat forage for stock feeding include sowing date, seed rate, soil preparation (including fertilizer management), grazing or cutting manage-

ment and grazing or harvesting time.

New Zealand and Australian oats are facultative types and most could be classified as short to mid-season maturing cultivars. However, with typical sowing of oats in autumn or early winter, development patterns are not dissimilar from long season types that require vernalization for floral initiation. Typically, crops are sown at 100 kg ha^{-1} and at rates of up to 150 kg ha^{-1} if direct drilled or broadcast.

BIOMASS PRODUCTION

A commonly grown New Zealand grazing oat, cv. Stampede, produces significant biomass before floral initiation when sown between late February (late summer) and early April (early autumn). The crop may require a period of vernalization, but this has not been quantified. Sowing dates for grain production of Stampede typically range from 1 April to 1 September. Flowering occurs over a short period, from 4 November to 2 December (de Ruiter *et al.*, 2000). The mechanism controlling flowering in this cultivar, and others used in the NZ market, are unknown, although there appears to be a dependence on increasing photoperiod or a critical day length for flower initiation. It is not known whether the crop will progress through to flowering when sown in early February. If flowering does occur, the chance of producing viable grain is much reduced in more southern areas because of frost damage.

Stampede has the capacity to produce a large leaf area and support higher aboveground biomass than selections with smaller leaves. However, oats generally have thick stems that may reduce their digestibility and palatability for stock. The crop should be used before the onset of stem elongation and before the rapid decline in feeding value that is directly related to the change in leaf to stem ratio with maturation. Light grazing by sheep is recommended at the first node stage, but good stock management is critical to minimize and reduce wastage and to allow re-growth. A single bite at the 2–3 node stage or later is the best grazing management option with cattle.

In small plot evaluation trials, single-cut harvests of cv. Stampede grown at Lincoln, Canterbury, on 1 July (1999) and 4 July (2000) from sowing in early March were 6.4 and 5.0 t ha^{-1}, respectively (Table 10.1). Yield of Stampede in the first year was higher than Hokonui (a very late maturing short, thin straw semi-dwarf forage cultivar used for grazing or silage) but comparable with Hokonui in the second year (Figure 10.4). Production rates in response to thermal time accumulation from plant emergence were 558 and 466 kg DM ha^{-1} 100°C $days^{-1}$ in the respective 1999 and 2000 growing seasons. The difference in productivity between years may be related to differing solar radiation. For example, during the equivalent period from 20 March to 1 July, an additional accumulated daily radiation of 51 MJ/m^2 was recorded in 1999 compared with 2000. The difference in radiation interception would account for an additional 1 t ha^{-1} biomass production, assuming a typical growth efficiency of 2 g/MJ. The cultivar Hokonui produced similar biomass in response to thermal time in both years (438 v. 448 kg DM ha^{-1} 100 °C $days^{-1}$, respectively).

The yields shown in Table 10.1 were achieved under good growth and management situations. Temperatures were significantly warmer than the long-term

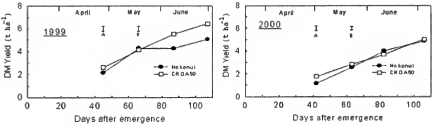

Figure 10.4
Biomass production for CROA50 (cv. Stampede) and cv. Hokonui in trials at Lincoln, New Zealand, in successive years. Standard Errors of Difference (SED) (5%) given are for harvest x cultivar interaction (A) or cultivar comparisons within harvest date level (B). Sowing dates were 4 March and 10 March, respectively.

TABLE 10.1

Comparison of biomass produced by cvs Stampede and Hokonui in successive years in Canterbury, New Zealand. Harvest dates for the respective years were 1 July and 4 July for crops sown on 4 March (1999) and 10 March (2000). Emergence was on 18 March and 20 March, respectively.

	Days after sowing	Emergence to harvest		Biomass	Production rate	
		(days)	(°C days)	(t DM ha⁻¹)	kg DM ha⁻¹/day	kg ha⁻¹ per 100 °C days
Year 1						
Stampede	119	105	1153	6.44	61.3	558.2
Hokonui	119	105	1153	5.05	48.1	438.1
LSD (5%)	-	-	-	1.19	-	-
Year 2						
Stampede	113	106	1080	5.03	47.4	465.6
Hokonui	113	106	1080	4.84	45.7	448.1
LSD (5%)	-	-	-	0.94	-	-

NOTE: LSD = Least Significant Difference.

mean in both years. The levels of biomass represent the upper range, given that in a grazing situation significant losses may occur from wastage and trampling.

In this experiment, no adjustment was made for residual biomass after grazing. The level of wastage can be minimized by only allowing stock to graze when the soil moisture is significantly below field capacity, or harvesting herbage in a cut-and-carry operation.

GRAZING

In situations where lactating or pregnant cows are being grazed, early autumn sowing of short-season cereals is a suitable option. Crops sown early in autumn showed good early growth in warmer soils and utilized the nitrogen mineralized during the establishment phase. Experimental blocks (2–15 ha) of cv. Stampede were sown alongside established cultivars on growers' properties in the lower North Island of New Zealand in 1999 and 2000. Biomass production was measured on plots cut to 2 cm above ground.

Biomass ranged from 3.6 and 7.9 t DM ha^{-1} (Table 10.2). Samples for biomass yield were all taken before 1 July,

and yields for cv. Stampede were up to 35 percent greater than the paddock reference cultivar (Table 10.2). Sowing dates were all within a relatively narrow period (13 March – 4 April). Crops were sown at rates of 95 and 110 kg ha^{-1}, with a range of fertilizers (e.g. 120 kg ha^{-1} of "Crop15", or 300 kg ha^{-1} super + 30 kg ha^{-1} urea). Establishment of Stampede was invariably better than the reference cultivar, with better early vigour.

FEED QUALITY

Trials conducted at Crop and Food Research have provided information on the changes in nutritive value of herbage during plant development. This information was used to determine the optimum time for harvest using quality of herbage as the prime variable for harvest decisions.

For autumn-sown small plot evaluation (sown 4 March 1999), samples were taken for quality at three-week intervals. Comparative data for quality of cvs Stampede and Hokonui are shown in Figure 10.5. There were no significant differences between the cultivars within harvest date for any of the quality variables tested. However, the effect of harvest time was strongly significant (P<0.001) for all variables. As the yield increased with maturation (Figure 10.4), there was an associated linear decline in quality. The protein content may be managed by use of N fertilizer, with the added advantage that yield will be increased. However, there is a potential for excessive leaf nitrate concentrations and nitrate poisoning in stock if oat herbage forms a high proportion of the fed diet.

Decisions regarding the timing of grazing will be difficult if making a choice for maximizing biomass or utilizing the crop before the quality declines to unacceptable levels. The best indicators of qual-

TABLE 10.2

Dry matter biomass production for experimental blocks of cv. Stampede sown alongside standard cultivars in the New Zealand North Island districts of Manawatu, Rangitikei and Wairarapa in autumn 1999 and 2000

Site	Sowing date	Sample date	Biomass (t DM ha^{-1})	Yield relative to paddock cultivar (%)
Year 1 (1999)				
1	13 Mar	21 Jun	3.8	110 [a]
2	13 Mar	16 Jun	5.2	108 [a]
3	22 Mar	16 Jun	4.6	110 [b]
4	26 Mar	16 Jun	4.4	120 [b]
5	20 Mar	24 Jun	5.2	124 [c]
Year 2 (2000)				
6	1 Apr	26 Jun	4.4	139 [d]
7	–	27 Jun	5.4	118 [d]
8	15 Mar	27 Jun	6.2	112 [e]
9	4 Apr	1 Jul	3.6	122 [e]
10	31 Mar	26 Jun	3.6	112 [f]
11	31 Mar	2 May, 29 Jun	0.42, 1.3	91, 111 [g]
12	23 Mar	28 Jun	5.3	99 [f]
13	20 Mar	29 Jun	7.9	–
14	20 Mar	29 Jun	4.4	–

Key: Control paddock cultivars were a = Awapuni, b = Caravelle, c = Makuru/Awapuni, d = Hokonui, e = Omihi, f = Awapuni, g = Finlay.

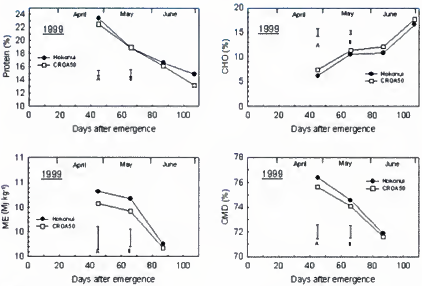

Figure 10.5
Changes in protein, total carbohydrate (CHO), metabolizable energy (ME) and organic matter digestibility (OMD) of autumn sown CROA50 (cv. Stampede) and cv. Hokonui in 1999 (sown 4 March). Vertical bars are Standard Errors of Difference (SED) (5%) for harvest × cultivar interaction (A) and cultivar comparisons within harvest date level (B).

ity are protein content and total soluble sugar (starch plus soluble carbohydrates). Metabolizable energy (ME; MJ kg^{-1}) is also a good general indicator of the value of the herbage for maintaining stock condition or for meat and milk production. ME declined significantly when crops were in the stem elongation phase. Protein also fell to less than 15 percent during this phase, and continued to decline during reproductive development.

In New Zealand, forage cultivar breeding and evaluation by Crop and Food Research is continuing. Research into the potential use of oat cultivars for enhanced dairy production has addressed the issue of pasture feed deficits during dry periods. Traditional breeding and selection is being used to generate new cultivars with desirable characters, such as disease resistance, improved cool season growth and improved quality.

Management strategies will be updated regularly to optimize nutritive quality and growth characteristics. Widely differing genetic potential of a range of crops, including a number of oat species, will be examined for their patterns of productivity and for changes in herbage quality in relation to growth conditions.

Animal response experiments in collaboration with Lincoln University are also planned to examine the benefits of altered production methods; to improve the use of forage cereals, placing greater emphasis on maintaining stock health by providing high quality herbage; optimizing dairy production through sound soil

Figure 10.6
Areas of oat production in Australia

management; and the use of appropriate cropping and pasture rotations to enhance the sustainability of production systems.

Cultivars produced for specific feeds, such as cut-and-carry, e.g. hay and silage, or grazing systems, will be supported by management guidelines and decision support systems for new growers contemplating the use of new crops or cultivars.

Programmes will also provide new cultivars with prescription quality and yield characteristics for specific production requirements, such as autumn, winter, summer and spring grazing, hay and silage use, and improved disease resistance. The outcome of these programmes will be more reliable and sustained milk and meat production by overcoming seasonal feed and production supply problems, and reliable seasonal supply for dairy cows to maintain the lactation peak for longer in the spring and enhance productivity in summer.

PRODUCTION AND CROP MANAGEMENT IN AUSTRALIA

The forage market

Oats in Australia have traditionally been grown in moist temperate regions. However, improved cultivars and management practices have enabled oats to be grown over a wider range of soil and climatic conditions (Figure 10.6). Fodder oat crops in Australia are sown in autumn and either grazed, or grazed and harvested for grain after the removal of livestock, baled or cut for chaff.

The fodder industry trading market has domestic and export sectors, both

of which are growing in size. Domestic fodder use is highest in all areas during the winter months, but can extend from autumn to early spring and summer, depending on seasonal conditions, animal reproductive cycles and farm stocking rates.

Buyers and on-farm users are becoming increasingly conscious of fodder quality. Dairy farmers in Australia and New Zealand are conscious of cost-effective feeding and many buy on the basis of metabolizable energy (ME) content, protein (CP) and dry matter digestibility (DMD). Objective analysis and subjective appearance of fodder are loosely related but their reliability as indicators of feed value can vary considerably (Stubbs, 2000). Palatability and digestibility are important price factors, particularly for the Australian export market, but are difficult to analyse accurately. In addition to objective measurements, appearance, smell, feel and the level of impurities, such as weed seeds, may influence "grades" and therefore pricing.

A range of hay types are traded according to end use. They include grass or cereal hay and straw for dry cows, and lucerne and various legume+cereal hay mixes for lactating cows and young cattle. Lower quality hay and silage are often used for cattle maintenance feeds.

End users

Feed lots are big users of traded feed grains, which are supplemented by roughage in the form of silage, hay and straw, sometimes at the lower-quality end of the supply range. About half the total feed lot activity is in Queensland, a third in New South Wales and the rest distributed between Victoria, South and Western Australia. Feed lots usually have extensive storage facilities for grain and fodder for year-round supply, and are located close to both grain and fodder producing areas.

Dairy farms, because of their relatively high stocking rates and the need to maintain lactating animal condition and production, are the biggest single buyers, but not the largest users, of conserved forage. The location of this market segment closely matches the main dairying regions in Australia, Victoria, New South Wales and Queensland. Seventy-five percent of conserved cereal is derived from oats (Stubbs, 2000).

The horse industry is also an important part of the domestic trading market. The racing industry and owners of horses used for recreational purposes buy fodder. This market segment is distributed around the urban centres, particularly Sydney and Melbourne, and major provincial and state capital cities.

Graziers running sheep and cattle on large properties aim for self sufficiency in fodder. The climate intervenes from time to time, resulting in either occasional large localized demands for purchased fodder or, less often, surplus fodder for the trading market. The interaction of climate, feed requirements and livestock numbers affects domestic fodder demand and supply, and therefore prices. When fodder must be purchased, there is little opportunity for graziers to discriminate on type and quality (Stubbs, 2000).

In Queensland, oats are grown as the main winter forage crop due to the state's warmer climate; hence farmers are able to produce good quality feed when most pastures are dormant. Farmers rely on oats for grazing in the dairy, sheep and beef

industries from late autumn to early summer. Only 10 percent of the crop is harvested for grain, primarily to provide seed for sowing (Platz and Rodgers, 1998).

Multigrazing

Multigrazed oat cultivars selected for use in Queensland grow rapidly and tiller well and, with careful grazing management, can be maintained in a vegetative state over a long period. Consequently, nutrient requirements, especially for nitrogen fertilizer, are higher for grazed oats than those required for grain crops.

State profiles

Crown rust is the major constraint on forage oats production in Queensland because the appearance and spread of the disease coincides with when the crop is needed for grazing. Managing the timeframes for crop grazing is one of the tools Queensland growers use to slow the spread of crown rust in the absence of cultivars with long-term durable resistance (Song, 2002).

Other major diseases affecting oats in Australia are stem rust, barley yellow dwarf virus (BYDV) and *Septoria avenae* blotch. There are crown and stem rust races that can attack all known resistance genes available to plant breeders (Zwer and Hoppo, 2002). Cereal cyst nematode (CCN) has been identified as a problem in some areas in South Australia, and recently in Western Australia.

New South Wales (NSW) is generally the largest oat producing state in Australia. Most crops are consumed by stock on the farm. Consequently, few crops are milled or exported to other states. The area of oats fluctuates widely with the profitability of the livestock industry.

Dual-purpose oats are sown in early autumn and grazed through to early winter, when reduced temperatures limit pasture growth. In late winter–early spring, as temperatures rise and alternative pastures become available for feeding, livestock are removed from the oat crop, which is then allowed to develop for grain production and harvest.

According to the Australian Bureau of Statistics, 354 000 ha of oats were sown in NSW in 1998, but this area decreased substantially in the following two years, rising again to 260 000 ha in 2001. In 1996, 50 percent of the oat crop was sown using dual-purpose cultivars, and this proportion of the total crop was likely to increase (McLean *et al.*, 2000).

In South Australia, Victoria and Western Australia, 97 000, 122 000 and 111 000 ha of oats were sown for hay, grazing and silage respectively. This growing local and export hay industry increasingly relies on improved and specialized cultivars to maintain and improve the ability of growers to meet quality specifications for export hay.

Oaten hay for internal trading, on-farm uses and for export are the major end uses for oat crops grown in these states. According to McLean *et al.* (2000), production of oats for export hay is likely to increase. Though riskier than grain production, greater financial returns can be achieved from hay production.

In Queensland, over 200 000 ha of oats are grown annually as the main winter forage crop, due to its ability to produce good quality feed when most pastures are dormant. Farmers rely on oat forage crops to produce feed for livestock fattening and finishing from early winter to spring. In this situation, average liveweight gains of

1 kg head^{-1} day^{-1} can be achieved (Song, 2002).

Cultivar development

Both Australia and New Zealand rely heavily on North American germplasm from oat improvement programmes. Oat germplasm from Canada and USA is well suited for fodder production, particularly for winter production. Selected parents for crossing or genotypes selected for release generally produce vigorous early growth (Oates, 2000).

Most plant breeding programmes in Australia develop cultivars suitable for both grain and fodder uses, whereas in Queensland, private and public oat breeding focuses almost entirely on oat forage cultivars for grazing.

Cultivar releases since introduction of plant variety protection

Registration of cereal cultivars, and hence the ability of cultivar owners, or their licensed agents, to collect royalties from seed sales, came later in Australia than in New Zealand. The introduction of Plant Breeders Rights (PBR) stimulated greater private sector involvement in forage oat cultivar development and releases, particularly in Queensland.

The selection of cultivars below is not a complete list of forage cultivars used in Australia, but illustrates the importance of the international linkages involved in oat crop improvement programmes.

CULTIVARS AND CROP MANAGEMENT

New Zealand

Introductions

Oat cultivars were brought to New Zealand and Australia by early settlers for porridge and feeding livestock. Cultivars were used for fodder and grain production (Wright, 1983). It was not unusual for an autumn-sown oat crop to provide winter grazing for livestock and then be left to regenerate to produce a grain crop for milling or animal feed. Only in recent years have oat cultivars been developed and released for specialty uses. Before that, certification of oat seed for purity was not standard practice. Consequently, cultivar integrity was easily lost and cultivars often became misnamed.

Crown rust resistance

A popular early oat cultivar in New Zealand was the English-bred Gartons Abundance. It was bred by Messrs Gartons and released in New Zealand in 1892. It was the first successful oat developed by hybridization and was the standard milling oat cultivar in New Zealand for many years.

Gartons Abundance was a rust-resistant cultivar widely used for livestock fodder, representing 58 percent of the New Zealand fodder market in the early 1930s (Hadfield and Calder, 1934). By 1934, it had become susceptible to crown rust and was replaced by cv. Algerian, which had improved rust resistance. Algerian is believed to have arrived in New Zealand from Algeria via Australia in the early 1900s.

In areas of the North Island where oats were badly affected by crown rust, Algerian was widely used as green feed for grazing, chaff, hay, silage and grain production (Claridge, 1972). In Canterbury, Algeria was autumn sown for early winter grazing, followed by a grain harvest for animal feed.

Oat selection and breeding

Observations made by merchants also revealed that Algerian was a mixed cultivar of distinct types. A reselection, College Algeria, was distributed by Canterbury Agriculture College, but this cultivar also became mixed and misnamed (Claridge, 1972).

The cultivar Ruakura originated from a rust-resistant single plant selected from the cultivar Argentina in New Zealand in 1908 at the Ruakura Farm of Instruction. It proved to have better resistance to rust than Algerian.

Overseas introductions contributed significantly to the portfolio of cultivars used for oat production in New Zealand and Australia, and toward the establishment of oat breeding programmes in both countries.

An oat breeding and selection programme was established at the Department of Scientific and Industrial Research (DSIR, NZ) in 1938. It was suspended during the Second World War, but resurrected in 1952 by G.M. Wright, who commenced a formal pedigree breeding and backcrossing programme for New Zealand.

Commercially important general purpose cultivars bred by DSIR include Oware (1963), Mapua (1965), Amuri (1967), Makuru (1970), Taiko (1971), Omihi (1977) and Ohau (1980). Cv. Caravelle was released in 1980 by a private company.

Cultivar releases were based on improved resistance to neck break and lodging (Makuru and Mapua), crown rust resistance (Amuri, Hattrick, Omahi and Ohau), improved grain and forage yield (Makuru), and tolerance to BYDV (Omihi and Ohau).

Oats in the 1950s

From the 1990s, oat cultivar breeding objectives focused on the development of cultivars for specialty end uses, such as milling, feed or forage. Otama was developed as a special purpose forage cultivar and released by the New Zealand Institute for Crop and Food Research Limited (CFR) in 1994. It had good resistance to BYDV, produced high yields of green feed, but did not compete well with Makuru for green feed uses outside Canterbury.

Otama was also crown rust susceptible, although at the early stages of rust infestation it appeared to suffer less from rust than Makuru, giving Otama a slightly longer grazing window before succumbing to crown rust (Keith Armstrong, pers. comm.).

Otama is also grown in the USA, in the Northern Pacific states, where crown rust appears to be less of an issue. There it is known as cv. Charisma.

Cv. Hokonui was released by CFR in 1997 for green feed, hay and silage. Hokonui is a very late maturing, semi-dwarf, forage oat cultivar with excellent straw strength. It is marketed throughout the South Island, but is also grown in the North Island, where it is moderately susceptible to crown rust.

Oats from the year 2000

Cv. Stampede was selected and released for use throughout New Zealand by CFR in 2000 as a rust-resistant green feed oat. It was selected by CFR in New Zealand from a cross developed by Agriculture and Agri-Food Canada in Winnipeg, Canada.

In yield trials, Stampede significantly out-yielded all cultivars in the South

Island. In the North Island, its yields are similar in volume to cv. Hattrick, and, together, these two cultivars make up most of the traded oat forage seed in the North Island.

Australia

Western Australia

Cv. Vasse is a tall semi-dwarf late maturing hay oat cultivar that was jointly developed and released in 1997 by Agriculture Western Australia, Grains Research and Development Corporation (GRDC), and The Grain Pool of Western Australia. Vasse is susceptible to crown and stem rust, CCN and stem nematode. Vasse has high hay yields in very high rainfall, long-season environments. It has thin straw and produces high quality hay with good digestibility, metabolizable energy and crude protein.

South Australia

Cv. Glider was released in 1998 jointly by the South Australian Research and Development Institute (SARDI) and Texas A&M University, USA, as a late maturing hay cultivar. Glider has good foliar disease resistance and tolerance to stem nematode, but is susceptible to CCN. Glider is adapted to high rainfall areas where CCN is not present.

New South Wales

Cv. Eurabbie is a dual-purpose oat released by Agriculture NSW for grazing and feed grain production. It is suited to higher rainfall hay production areas where CCN is not present. It is moderately susceptible to crown and stem rust.

Cv. Enterprise was selected by CFR in New Zealand from a cross developed by the Canadian Department of Agriculture and released by Heritage Seeds in NSW in 1992.

Cv. Heritage Lordship is a forage cultivar selected by CFR in New Zealand from a cross developed by Agriculture and Agri-food Canada, Winnipeg, and released by Heritage Seeds in NSW in 2000.

Queensland

Cv. Culgoa II is a forage type released by the Queensland Department of Primary Industries (QDPI) in 1991. It was reselected from Culgoa, an introduction from Texas A&M University, USA.

Cv. Cleanleaf is a tall, late forage type that was released by Pacific Seeds in 1991, from a cross developed by the Crop and Weed Sciences Department of North Dakota State University, USA.

Cv. Riel is a tall, spring forage cultivar selected and released by QDPI in 1991 from a cross developed by the Canadian Department of Agriculture.

Cv. Nobby is a tall forage oat cultivar with a prostrate growth habit released by QDPI in 1992 from a cross developed by Texas A&M University, USA.

Cv. Condamine is a spring forage oat released by Pacific Seeds, from a cross developed in Brazil.

Cv. Graza 50 is a tall spring oat released by Pioneer Hi-Bred in 1993, from a cross developed by North Dakota State University, USA.

Cv. Graza 70 is a tall spring oat released by Pioneer Hi-Bred in 1993, from a cross developed by the Canadian Department of Agriculture.

Cv. Barcoo is a short-season, spring oat with a prostrate growth habit that was selected and released by Pacific Seeds, Queensland, in 1995, from a cross

developed by Texas A&M University, USA.

Cv. Moola is a tall hay and forage oat with CCN resistance released by QDPI in 1996, from a cross developed by Agriculture and Agri-Food Canada. Moola is widely adapted as a hay cultivar in most of the hay producing regions.

Cv. Graza 68 is a grazing cultivar released by Pioneer Hi-Bred in 1997, from a cross developed by Agriculture and Agri-Food Canada, Winnipeg. At the time of release, Graza 68 was recommended as being adapted to most areas of Australia, and particularly those where high incidences of crown and stem rust are encountered.

Cv. Gwydir is a semi-prostrate prolific tillering cultivar selected from the University of Queensland's pedigree breeding programme. It was released by Pacific Seeds in 1997. It is a late maturing, early vigour, grazing cultivar. At the time of release, it was resistant to crown and stem rust.

Cv. Warrego is a late maturing, grazing cultivar that was selected and released by Pacific Seeds, Queensland, in 1997, from a cross developed by the NDSU Research Foundation, North Dakota, USA. At the time of release, it was resistant to crown and stem rust.

Cv. Nugene is a tall grazing cultivar selected and released by QDPI in 1999, from a cross developed by NDSU Research Foundation, North Dakota, USA.

Cv. Taipan is a grazing cultivar selected and released by Pacific Seeds in 2001, from a cross developed by NDSU Research Foundation, North Dakota, USA.

Miscellaneous cultivars released in Australia before the introduction of plant variety protection

Cv. Swan was released in 1967. It has widespread adaptation as a hay oat, with good digestibility, but lower protein than other hay cultivars.

Cv. Saia is a diploid oat thought to have been introduced from Brazil. It is widely used as a hay oat. It has very thin straw, and better protein but poorer digestibility than cv. Swan.

Cv. Esk, released in 1975, has limited application as a hay oat for longer-season environments.

Cv. Winjardie was released in 1985 as a hay and grain oat. It has thin straw, with similar digestibility to cv. Swan, but higher protein.

Cv. Kalgan was released in 1988 for hay or feed grain. Its thick straw makes it unsuitable for export markets, but it has similar digestibility to cv. Swan, with high protein.

Cv. Hay was released in 1988 for hay production and has a consistently high yield, but its thick straw may make it unsuitable for export markets

RESEARCH IN NEW ZEALAND AND AUSTRALIA

Oat breeding programmes are based at Christchurch, New Zealand; Toowoomba, Queensland; Temora, NSW; Adelaide, South Australia; and Perth, Western Australia. The barley breeding programme in Tasmania also undertakes some oat improvement.

The Australian programmes exist within government departments of agriculture, while the New Zealand programme is within a government-owned research

Figure 10.7
Crop and Food Research Ltd, New Zealand, cereal seed production plots

company, the New Zealand Institute for Crop and Food Research Limited (CFR) (Figure 10.7).

In Australia, private industry involvement in oat breeding and selection is limited to Heritage Seeds, Pacific Seeds and Pioneer Hi-bred. There is no known private oat breeding currently undertaken in New Zealand.

New Zealand

Efforts in oat breeding are limited by industry size. There is one full-time oat plant breeder at CFR, Lincoln, close to Christchurch. The programme focuses on forage, milling and novel food grains.

The programme has been very successful, with approximately 95 percent of oat production for forage, feed and milling oats in New Zealand based on CFR cultivars. Cultivar releases have been made in Australia and the USA.

The programme focuses on crown rust (Figure 10.8) and BYDV in all regions, and stem rust and *Septoria avenae* blotch to a lesser extent.

Stem rust, *Puccinia graminis*, is a potential future threat to oat grain crops and resistance is being added to new populations. Though it is not yet a problem in commercial crops, stem rust is appearing more frequently within the breeding nurseries. Germplasm derives mainly from North America, and segregating populations are developed using both pedigree and bulk breeding methods.

ROSS HANSON

Figure 10.8
Rust tolerance (left) versus rust susceptibility (right). An autumn-sown oat grazing crop in the North Island of New Zealand in the winter of 2001

Genotypes are selected for evaluation and potential commercialization by collaborating companies in New Zealand, Australia, USA and the UK.

The small novel oat grain cultivar breeding component is closely aligned to CFR's food science programmes. The focus is on alternative processing systems and new food uses for the oat crop. The forage programme is developing oat cultivars specifically suited for more frequent winter grazings to meet the changing and expanding demands of an increasingly sophisticated livestock industry.

Australia

Queensland

The University of Queensland is mainly involved in screening lines from other sources for their suitability for forage production, mainly in Queensland. The oat breeding programmes are developing cultivars that combine crown rust resistance and improved forage yield and quality. As well as producing cultivars suitable for grazing, cultivars suitable for hay production are being selected.

Cultivars for grain production are not a priority as only limited grain production occurs in Queensland. The major focus of the programmes is to develop cultivars with more durable forms of resistance to crown rust, and the approach chosen by QDPI is to "pyramid" resistance genes. Molecular markers are being used to select lines with multiple resistance genes, and these are then advanced for assessment of forage yield.

National Cereal Rust Control Programme (NCRCP)

The NCRCP is managed by the University of Sydney and is based at Camden. The major crop of interest is wheat, but limited resources are available to oat breeders. Each year, the NCRCP conducts a survey of races of crown and stem rusts prevalent in Australia, receiving samples of rust on oats and wild oats from collectors across the country, as well as from New Zealand. Results of the survey are published each year, guiding breeders in their decisions about the use of rust resistance genes.

The NCRCP also provides a screening service to breeding programmes. Glasshouse and field screening for both crown and stem rusts are conducted each year, with results – and in some cases resistant selections – being returned to the originating breeding programme. This service is of particular value to the Perth-based programmes as rust epidemics for screening are not reliable in Western Australia (McLean *et al.*, 2000).

The NCRCP programme is also investigating alternatives to single-gene resistance to the rusts, and screens related wild species for new sources of resistance.

New South Wales

The NSW oat breeding programme at Temora has concentrated mainly on dual-purpose oats for grazing and grain, with less emphasis on grain oats. While NSW is regularly the largest oat producing state in Australia, only a small quantity of the crop is either milled or exported from this state, the crop being largely used on-farm. This has resulted in very poor oat grain prices in NSW. Thus, in the absence of grower contracts to produce milling oats, farmers in NSW consider oats uncompetitive with other, higher value crops such as canola or wheat, unless oat crops can be used to provide grazing to livestock throughout autumn and winter.

Major disease problems are crown and stem rusts and BYDV. The NSW programme now focuses on dual-purpose oats and is placing increased emphasis on selecting for winter growth habit, disease resistance and grain quality parameters that are important in animal production. This will include metabolizable energy and digestibility if resources are available.

South Australia

The South Australian programme is the largest oat breeding project in Australia and set to become Australia's major oat breeding centre. It is based in Adelaide at an integrated university and state agriculture department facility. Interactions exist with scientists trained in a broad range of disciplines who are located at the Waite Precinct. Funding for the programme comes from state government, the Grain Research and Development Council (GRDC), the Rural Industries Research and Development Corporation (RIRDC) and private companies.

The programme is developing improved husked and naked grain oat cultivars with enhanced milling and feed quality, improved disease resistance and increased yield potential for the diverse agro-ecological zones in south-east Australia. The programme is also developing improved hay oat cultivars, with grower and industry support from Victoria and, more recently, Western Australia

A growing export hay industry from South Australia and Victoria relies on

improved hay cultivars. Hay is also an important fodder reserve. These new cultivars should be of high quality so that first grade hay can be reliably produced, and economic losses due to down grading avoided.

For both grain and hay cultivars, the South Australian programme aims to improve resistance to crown and stem rusts, CCN, stem nematode, root lesion nematode, BYDV and bacterial blight. These diseases are seen as major factors limiting yield and quality for both grain and hay production. Both resistance and tolerance to nematode diseases are also required. Routine screening programmes are in place for the nematode diseases. Breeding lines are evaluated with specific pathotypes for resistance to crown and stem rusts and BYDV, in cooperation with the University of Sydney's NCRCP. The South Australian oat breeding group also takes advantage of regular natural epidemics in field trials to assess breeding lines.

Quality characters are important in the development of hay cultivars. Traits such as digestibility, palatability, stem diameter, hay colour, neutral detergent fibre (NDF), water soluble carbohydrate, and shear energy are among the quality characters assessed for the most advanced breeding lines (Zwer and Hoppo, 2002).

The South Australian programme is involved in cooperative programmes to improve the efficiency of the oat crop using the maize doubled-haploid methodology, and the development of molecular markers for CCN resistance and tolerance, stem nematode tolerance and quality characters.

Research is also underway in South Australia to improve the efficiency of oat haploid production. The doubled-haploid technology will be used to develop mapping populations and to create homozygous lines for selected elite crosses. This technology is expected to reduce the time needed for oat cultivar development.

A major benefit of developing and using molecular markers is the ability to "pyramid" disease resistance genes. The other technology to be explored is the use of transformation as a means of introducing effective stem rust resistance into oats.

The food industry requires cultivars with better milling yield, higher protein and β-glucan content, with low oil content. The feed industry is looking for higher-oil-content cultivars. Improved hay quality is essential for the growth of the export hay market. Identification of characters that improve palatability or preference is a particular priority for hay quality improvement.

Western Australia

Both Agriculture Western Australia (a state department) and GRDC, previously a major funding partner, recently reviewed and restructured the Western Australian oat breeding programme. Milling quality was the key focus of the Western Australia programme, but, more recently, researchers have improved and widened their quality testing methodology, and improved their understanding of what makes a good milling quality oat. Reliable near-infrared (NIR) calibrations have been developed for whole grain groat percent, moisture, protein and oil content. Quality is also an important consideration when developing hay cultivars, so work has focused on stem thickness, protein content, digestibility and metabolizable energy.

The programme has been very successful, with 95 percent of oats in the southwestern region being bred by Agriculture Western Australia. In the future, work on feed oat cultivars will be decreased and resources redirected to the development of cultivars suitable for the export hay industry.

There are major environment, soil type and disease pressure differences between the western and southern regions of Australia, creating the need for effective regional testing programmes to service these diverse regions. Western Australia's focus is on export rather than domestic markets, due to its small population and lack of extensive domestic manufacturing. As a result, Western Australia is a significant exporter of both grain oats and oaten hay. This focus is reflected in industry partnerships, major partners being Agracorp, Australia's largest grain oat exporter, and Quaker Oats Australia, which has a food export focus.

Diseases considered important in Western Australia include stem and leaf rusts, BYDV and *Septoria avenae* blotch, with bacterial blight of more minor importance. Disease resistance has not been a strong point of the breeding programme, though this has changed with the increased frequency of epidemics of diseases such as leaf rust. A nursery is set up each year to screen lines for resistance to *Septoria avenae* blotch.

The Western Australian programme team has worked closely with an oat agronomist and growers to provide growers with production packages for new oat cultivars, and to improve grower awareness and adoption of agronomic practices to improve both yield and quality of milling and fodder oats.

CONCLUSIONS

Oat production is likely to be more concentrated in areas where oats have a natural advantage over other crop species. Oats have advantages in waterlogged environments and are tolerant of frost and acid soils, particularly where aluminium toxicity occurs. Oats also fill an important role in forage production due to their ability to continue to grow in cold conditions.

Production of oats for export hay in Southern Australia is likely to increase. Though more risky than grain production, greater returns can be achieved from hay production, and new markets are still being developed. Markets have also been developed for second-grade hay, and this has reduced some of the risks associated with hay production. With the development of herbicide-resistant weed species, hay also offers a useful non-selective strategy for weed control, with the crop and weeds being cut before seed set.

Oats are an important break crop to control CCN and Take-all diseases in South Australian and Victorian rotations, particularly in low rainfall areas, where there are few feasible rotation crops.

In the northeastern parts of Australia and the North Island of New Zealand, oat production is limited by the lack of sources of effective resistance to crown rusts (and stem rust in Australia) due to the rapid evolution of virulence by the pathogens. New approaches to develop more stable and durable forms of resistance are essential, given the rapid breakdown of single-gene resistances.

Oats can contribute to animal nutrition as a grazed forage, silage, hay and chaff. They have the advantage of early biomass yields in autumn sowings and are used

to complement maize in a double-cropping silage system in the North Island of New Zealand. Oats are a flexible crop that allows different harvesting options, depending on current feed supply. The disadvantages include a lack of cultivars developed specifically for intensive multiple grazing situations in cooler regions.

Oats, like other cereal crops and brassicas used in intensive production systems, can cause nitrate poisoning in cattle (Clark, Thom and Roche, 2000). Plants that contain from 1.0 to 1.5 percent potassium nitrate on a dry matter basis may cause acute toxicity in ruminants. Generally, unless other factors are involved that predispose animals to toxicity, stock may consume fodder crops without ill effect. Ruminants can tolerate high levels of nitrate if intake is spread over the whole day. Therefore, for feed high in nitrate, gradual introduction is recommended.

Governments in Australia and New Zealand are reducing their investment in plant breeding programmes for all crops. As a result, there are likely to be closer Australian and New Zealand industry alliances, with the creation of new joint ventures involving research institutes and stakeholders in both countries. Given the small size of the oat industry in New Zealand and Australia relative to wheat and barley, and its lower potential for royalty income, reducing public investment in genetic improvement will increase the urgency for application of enabling technologies such as molecular markers, double haploids and transformation. It will also increase commitment to pursue shared goals through national and international collaboration.

Increased interactions with industry and end users in the future will (from the New Zealand experience over many years) provide more clearly defined quality and commercial goals. The future success of breeding programmes is dependent on retaining access to international germplasm pools. Germplasm exchange between breeding programmes and the operation of international commercial shuttle nursery programmes between the Northern and Southern Hemispheres enables breeders to evaluate breeding populations in contrasting environments and to rapidly advance breeding plant populations, as a means of speeding up the process of releasing cultivars.

Characterizing and documenting germplasm, including plant breeders' collections, for all the important food and forage crops of the world will continue to require some government and international agency funding, both for maintenance and for higher-risk research activities. This is of current concern in New Zealand, where state funding systems are becoming less supportive of the genetic improvement of plant material upon which the pastoral and food industries are based.

Increased regulatory border controls surrounding the movement of crop seeds for research and commercial activities into New Zealand and Australia are also beginning to restrict some research activities, and are adding substantial costs through additional quarantine compliance requirements. The benefit, however, is the improved security against introduced pests and diseases that such controls provide for our agricultural and horticultural industries.

An essential requirement for future successful breeding programmes is plant breeders. In Australia and New Zealand,

there is an aging population of plant breeders and little succession planning by organizations. It is essential that investment be made in training new plant breeders, ensuring new entrants have the necessary breadth of knowledge to succeed.

Chapter XI
Fodder oats in Europe

Atanas Kirilov

SUMMARY

In Europe, the same varieties of oats as are used for grain are usually used for fodder. They are the preferred companion crop for peas and vetch because of their coarse stems. Oats are most important in cold, northern countries. Areas are decreasing since maize and barley provide more of the higher energy feed required for intensive livestock production, and fully mechanized silage has largely replaced hay. Oats retain their importance as winter fodder in Mediterranean climates, where they may first be grazed and then grown on for grain. Oats have adequate soluble carbohydrates to make good silage, but are difficult to consolidate to provide good anaerobic conditions for ensiling.

INTRODUCTION

This chapter presents a review of the current and prospective importance in Europe of oats used as whole-crop forage.

Oats (Figure 11.1), like rye, came into cultivation later than wheat and barley. The cultivated species are descended from the wild forms that were probably found as a weed in cultivated cereals in the Mediterranean region, Asia Minor, North Africa and Transcaucasia. Oats are an annual cereal, widely grown for grain (Figure 11.2), which is mainly used as food for livestock, and to a lesser extent for humans. Whole-crop oats are a good source of forage and many farmers use it as hay, silage or pasture for cattle and sheep. Oats grew to importance because of their suitability for feeding horses, and were the preferred grain feed for the horses that were the main means of work and transport in time of peace and war.

The fact that the nutritive value of a kilogram of medium-quality oats was chosen in 1922 in the former Soviet Union as a Feed Unit, called also Russian Feed Units, and the use of Oats Feed Unit (1 425 kcal) as reference value for Kellner's system in Germany, also speaks for the popularity of oats as feed grain. Later, the Oats Feed Unit was introduced into Bulgaria, Yugoslavia and some other countries. In a similar way, barley was accepted as a Feed Unit (1 730 kcal) for reference to estimate the energy nutritive value of food for ruminants in countries such as France, Belgium and the Netherlands.

The oat grain is a good source of protein, starch, fats and vitamins (B_1, B_2). It is used as flakes, flour and meal for human consumption, and as a coffee substitute, but it is fairly low in gluten, so it is not suitable for making bread, but is made into oat-cakes. It is present at breakfast as cereal porridge and in special varieties of bread. There has been an increase in oats used for human food. Human consumption of oats is important in some countries, such as the United Kingdom (41 percent of total production in

Figure 11.1
*Oats (*Avena sativa *L.)*

1993–94 (Valentine, 1995) and 49 percent in 2000 (Valentine and Mattsson, 2000)) and Germany. The grain is also good for people with stomach problems and for reducing blood cholesterol.

Oat grain is very good dietetic food for young ruminants because of its high hull and fibre content. It is recommended that a small quantity be fed during the suckling period to habituate young ruminants to consumption of forages and to develop their rumen. The presence of a larger quantity of cellulose in the grain coat dilutes the nutritive energy value of oats compared with barley, for instance. Oat grain can be used in a quantity of 4 to 8 kg in the daily ration of horses, up to a third of ruminant rations, but should not exceed 15–20 percent in the feed of pigs and poultry.

Fodder oats are grown for whole-plant use for grazing, green forage, silage or hay, as well as for grain. They are often used in mixture with legumes for forage production. The straw is important bedding for livestock, as well as good roughage. The growing of whole-crop oats gives livestock farmers the opportunity to have additional forage resources in dry summer weather, when yield from conventional forage crops is restricted.

Characteristics

There are many species of *Avena* (about 70), but only a few are of economic and practical importance. All are annuals and belong to one of three groups according to their chromosome number (Maksimovich, 1998):

- Diploid 2n = 14 chromosomes (*Avena strigosa; Avena strigosa brevis; Avena clauda; Avena longiglumis*),
- Tetraploid 2n = 28 chromosomes (*Avena strigosa weistii; Avena barbata*) and
- Hexaploid 2n = 42 chromosomes (*Avena sterilis; Avena byzantina; Avena fatua; Avena sativa*).

Avena sativa L. has the widest distribution as a crop in Europe (about 90 percent of all oat production), with *A. byzantina* occupying most of the balance (ca 10 percent). Small oat (*A. strigosa* Schreb.) and naked oat (*A. nuda* Hojer) are also found.

Oat development as a crop is similar to that of wheat and barley. There are spring and winter forms growing in areas with mild winters, such as UK, Portugal and the Mediterranean region. In contrast to wheat and barley, oats are less frost resist-

Figure 11.2
Oats being grown for grain

ant and die at temperatures below minus 14°C. When assessing suitable cereal components for the winter pea variety Pleven 10, it was found that when the minimum winter temperatures reached -18– -20°C, only 64 percent of the overwintering oat plants (*A. sativa*) survived, compared with 100 percent for rye, 75 percent for triticale and 65 percent for barley (Sachanski and Kirilov, 1988). High temperatures also exert an unfavourable influence on oats, particularly during flowering: at 35–38°C, it is less hardy than wheat.

The water needs of *A. sativa* are greater than those of barley and wheat. For seedling emergence, oats require more moisture than barley. In order to germinate, the oat grain must take in 65 percent of its weight in moisture, while barley emergence occurs at 50 percent. The greater requirement of oats for moisture explains why the crop finds optimum conditions in the moderate and humid climate of Europe and in regions of higher rainfall. The moisture needs of *A. byzantina* are lower and it is better adapted to the drier, hot climate of the Mediterranean and North Africa.

In contrast to the other closely-sown cereals, oats has a better-developed root system that penetrates to greater depth and uses soil moisture and nutrients better, so while not a good pioneer crop on poorer soils, it is good in the crop rotation. In some cases, oats are used as a nurse crop for sward establishment. There is a positive relation between the degree of root system development and above-ground biomass. The roots show a great assimilative ability with regard to soil nutrients. Oats are adapted to a wide range of soils and can grow on light, medium and heavy soils, and can thrive in neutral as well as acid and basic soils.

The most popular oat type in Europe is *A. sativa*, bred and grown mainly for

Figure 11.3
Oats growing in mixture with peas

grain, and the same cultivars are used for grain as for forage. In Europe, few institutes and companies are engaged in oat breeding, and in particular of fodder oats. The reason is the limited demand and distribution of oats for forage, which also includes low return on the funds put in. In UK, oats are included in breeding programmes, and growing oats for human consumption is important. At the Institute of Grassland and Environmental Research (IGER), Aberystwyth, Wales, UK, oat cultivars are developed for human consumption and for feeding to ruminants as well as for monogastrics (Cowan and Valentine, 2001). For ruminant feeds, breeding projects are directed to the development of thin-husked oats, with high digestibility. The best criteria for selecting cereal cultivars for whole-crop silage are, therefore, to select those with a high yield, good diseases resistance and good resistance to lodging (Ingram, 1990).

Oats are preferred companion crops in mixed stands with peas and vetch because of their strong stems. The sowing of oats in a mixture with peas (Figure 11.3) or vetch has a dual effect: the presence of oats minimizes the lodging of peas and vetch, so decreasing harvesting losses and increasing yield, and the overall nutritive value of the forage obtained is improved compared with pure stands of either constituent (Sachanski and Kirilov, 1988). As a companion crop, oats are suitable for peas and vetch since their maturity coincides. Oats can be established as both spring and winter mixtures with peas or vetch. A major disadvantage is the difficulty of choice of herbicides for weed control, but this disadvantage decreases with the earlier harvesting of the mixed stands for forage. Due to their lower winter hardiness, oats are not suitable for winter mixtures with leguminous crops in countries with cold winters.

TABLE 11.1
Oat production in Europe

	Area of oats ('000 ha)				Production of grain (tonne)			
	1989–91	1999	2000	2001	1989–91	1999	2000	2001
Albania	13	10	11	11	12	13	14	14
Austria	63	36	33	31	240	152	118	118
Belgium+Luxemborg	18	12	9	10	64	49	47	42
Belarus		293	300	300		368	491	600
Bosnia Herzgovina		29	26	26		62	57	54
Bulgaria	36	33	42	26	74	52	55	35
Croatia		24	20	22		57	47	51
Czech Republic		54	50	49		179	136	151
Czechoslovakia	95				366			
Denmark	24	26	45	45	114	130	233	150
Estonia		61	53	56		71	117	84
Finland	414	404	400	423	1420	990	1413	1287
France	220	114	103	117	867	514	459	486
Germany	471	268	237	232	1994	1339	1087	1138
Greece	43	44	46	47	73	86	86	78
Hungary	48	71	58	61	149	180	97	150
Ireland	22	20	18	18	140	136	128	120
Italy	157	142	141	139	318	331	318	305
Latvia		47	46	51		66	80	90
Lithuania		51	44	48		67	83	90
Macedonia FYR		3	2	2		4	3	3
Moldova Rep.		4	4	3		5	2	3
Netherlands	5	2	2	3	22	14	13	15
Norway	131	91	96	97	531	355	410	389
Poland	745	572	566	531	2059	1446	1070	1331
Portugal	101	83	85	77	92	100	113	45
Romania	153	248	232	250	220	390	244	520
Russian Fed.		3903	4082	4073		4 397	6 000	8 010
Slovakia		23	21	18		48	25	36
Slovenia		2	2	2		6	5	5
Spain	344	410	427	441	474	531	952	659
Sweden	375	306	291	271	1 489	1 053	1 151	961
Switzerland	11	6	5	4	57	28	27	20
UK	109	92	109	112	527	540	640	615
Ukraine		529	481	521		760	880	1 100
Yugoslav SFR	138				270			
Yugoslavia		67	63	63		122	96	96

DISTRIBUTION

Oats ranks sixth or seventh by area and importance in the world after wheat, maize, rice, barley and sorghum. In some countries, such as Finland, it ranks second, and in Bulgaria it ranks fifth. Oats are mainly grown for grain, but can also be used as a whole crop for green forage or silage. Europe is the place where oats is grown on the greatest area; North America ranks second and Africa last. In Europe, most oats are grown in the Russian Federation, Poland, Ukraine, Finland and Spain (Table 11.1).

During the last decades the areas sown with oats has decreased steadily, in the world and in Europe. For example, during 1934–1938, the area sown with oats averaged 58 100 000 ha, in 1967, there were 31 679 000 ha and 25 583 000 ha in 1986 (Maksimovich, 1998). In this period, in some regions, such as Sardinia in Italy, the area increased during 1940–70 because of an increasing dairy sheep flock. Steep slopes were cleared of scrub or native pasture to sow annual forages, including oats, but this increased the problem of soil erosion (Porqueddu, Sassari, Italy, pers. comm.).

Currently there is still a tendency for the oat-sown area to decrease. From 1990 to 2000, in only ten years, the area in the world occupied by oats decreased from 20 600 000 ha to 12 700 000 ha, i.e. by about 40 percent. However, as a result of the increase in average yield during the same period, the decrease in grain production was only 27 percent (FAO, 2002). The worldwide tendency for oat areas to decrease at the expense of other forages, particularly maize for silage (Poole, 1990), is also apparent in Europe (Table 11.1) (FAO, 2002).

There are several reasons for the fall in oat area in the world and Europe:

- The number of work horses has dropped sharply, along with the need for oats for feed.
- In human nutrition, oats are of less interest than wheat or rice.
- Contemporary livestock rearing is characterized by highly productive, high-yielding animals that need forage with high concentrations of energy and protein.
- New cultivars of maize and barley have been developed that have a higher nutritive value and can be grown in the areas occupied traditionally by oats.
- In energy yield per unit area, oats are inferior to maize for silage, and a feed unit from whole-crop oats is often more expensive than that from maize silage.
- Ensiling – a completely mechanized, easy method for conserving green forages – has replaced in great part the haymaking formerly important for animal feed in winter. Maize became the most widespread silage crop due to its indisputable qualities: high yield, high-energy concentration in DM, high content of water-soluble carbohydrates and ease of ensilage.
- The area occupied by silage maize increased considerably during the last thirty years and, together with pastures based on ryegrass, they became the main forages for ruminants, particularly dairy cattle in contemporary intensive stock raising in Europe.

Against the background of the situation described above, there are no exact data on the areas sown to oats intended for use as whole-crop forage. Many farmers produce and use their own oat seed, in particular for mixtures with legumes. An additional difficulty for accurate statistics is that in official statistics oats are classified as a grain, alongside wheat, barley and other cereals.

In the Czech Republic, 10 percent of oats are grown for forage, mainly as a nurse crop for clover and legume+grass mixtures for silage (A. Kohoutek, Prague, pers. comm.). The same use of oats for whole-crop silage is found in Slovakia (M. Polak, Grassland and Mountain Agricultural Institute, Slovakia, pers. comm.). In Greece, the share of oats used for hay or grazing is considerable, and the

TABLE 11.2
Use of fodder oats in Greece (data for 1992).

Use	Cultivated area (ha)	Production (t)
For grain	42 300	77 000
As hay	19 600	66 000
For grazing	31 300	–

Source: National Statistical Service of Greece, 1995.

production obtained represents a considerable proportion of forage (Table 11.2)

Oats are grown in Greece, especially in western Greece, which receives higher annual precipitation than the rest of the country (Papanastasis, Aristotle University of Thessaloniki, pers. comm.). In Greece, two species of *Avena* are cultivated: *A. sativa* and *A. byzantina*. In recent years, there has been growing interest in using oats in extensive farming systems. In Portugal and Spain, some oats are grazed in winter and thereafter are harvested for grain or hay. This reflects the emergence of new cultivars that have a great capacity to produce biomass at the beginning of the cycle and an excellent re-growth capacity after grazing. In the most intensive systems, as in dairying regions, oats have become a ryegrass substitute and are used as a second crop to grain. Oats are sown in autumn, harvested for silage in May, then the land is used once again for maize grain or silage. An increase in the oat area is expected (M.T.P. Dentinho and O.C. Moreira, Estação Zootécnica Nacional, Fonte Boa, Portugal, pers. comm.).

In Mediterranean regions where forage systems are mainly based on natural and sown pastures, a small portion of the animal feed is sometimes provided by annual forages. These are usually mixtures of cereals (barley and oats) and annual legumes (vetch, and crimson and berseem clovers) (Porqueddu and Sulas, 1998).

In other countries, such as Germany (Spatz, pers. comm.) and Slovenia (B. Kramberger, University of Maribor, pers. comm.), the use of fodder oats is symbolic. Because of their low nutritive value, oats are not a crop of choice for silage in Denmark (Søegaard, pers. comm.), but are used in mixtures with peas in feeding dairy cows in Sweden (Rondahl and Martinsson, 2003). In Estonia, oats are not used for grazing, green forage (zero grazing) or haymaking, but are occasionally used for silage (Selge, pers. comm.). In Latvia, oats are used mainly as a nurse crop when establishing meadows and pastures, and for green mass when grown in mixtures with peas and vetch, and for grain production in pure stands (A. Adamovich, Latvia University of Agriculture, pers. comm.). In Latvia, oats are very rarely used as silage or hay.

In some regions of the Russian Federation, mixtures of oats and peas, vetch or rape are used in rotation with other forages, such as rye for zero grazing, maize for silage or barley as a catch crop, to obtain 2–3 additional forage harvests per year (Novoselov, Rudoman and Lobanov, 1988; Kuvshinova, Arharova and Rozanskaja, 1987). Forage systems like this make for better use of machinery, better use of soil moisture and nutrients, and protect arable land from water and wind erosion.

Potential of oats as forage

The dry mass yield and nutritive value of forages are a determining factor for the farmer when choosing forages. These characteristics depend on the species and composition of forages, climatic and soil conditions, the suitability for intensive growing, mode of use and

many other factors. The lower nutritive value of oats compared with silage maize, wheat or barley has often been strongly emphasized as a cause for the decrease in the area and interest in oats as feed and forage. The nutritive value of oats almost equals that of triticale and rye, in terms of the net energy content per kilogram of dry matter at the same developmental stage (milk stage). However, it is about 70 percent of that of maize, 80–85 percent of that of barley and 90 percent of that of wheat.

Nutritive value

The nutritive value or feeding value of forages is a generalized concept that could be considered as a combination of chemical composition, digestibility and intake (the dry matter quantity from a given forage that can be ingested by the animals when fed *ad libitum*).

Feeding value = chemical composition + digestibility + intake

Many other forage characteristics are of direct or indirect importance to the nutritive value: the species, plant morphological composition, the physical form in which the forage is offered to animal, whether the forage is offered fresh or after preservation as silage or hay, the quality of silage affecting intake and digestibility, forage pollution with soil, the proportion of inedible plants and weeds, etc.

When studying the changes in the composition and nutritive value between flowering and grain ripening of whole-plant oats, wheat and barley, Demarquilly (1970) found that the dry matter content increased from 15–20 percent during flowering to 35–40 percent at the dough stage. During the growing season, the crude protein (CP = N × 6.25) and crude fibre (CF) content decreased, whereas the amount of starch increased. During this period, according to the same author, the crude protein content of oats decreased from 10 to 7 percent of dry matter (from 12 to 9 percent in wheat and barley) and crude fibre fell from 33 to 27–28 percent. Similar data for CP and CF content are also given in the French tables of forage composition and nutritive value of forages for ruminants (INRA, 1988) and in Bulgarian tables (Table 11.3). These values are lower than those determined by the author in Bulgaria, and shown in Table 11.4. CP content decreases during the whole growing season of oats and that of crude fibre increases until the beginning of grain formation, and then decreases slightly.

This outcome for cereals reflects a natural situation where the grain's development and the increase of its proportion in the total plant mass compensates for the fibre increase in the stems, so the fibre content decreases in the whole plant. The crude protein content of the grain due to presence of the glumes is low and does not lead to significant changes in the CP content of the whole plant. Staples (1989) reported data similar to this author's results for the CP content in oats, which were 20.5 percent CP at the boot stage, 14.6 percent at the milk and 11.9 percent at the dough stage. It is impressive that, in the more recent studies, the protein content in the whole plant is higher than that indicated in the studies of Demarquilly (1970) or in the tables for forage nutritive value by INRA (1988) or Todorov (1995), probably due to use of newer cultivars and better agricultural practices.

The content of water-soluble carbohydrate (WSC), which has a direct relation

TABLE 11.3
Composition of oats

Maturity stages	Crude protein g kg DM[1]	Crude Fibre g kg DM[1]	NDF g kg DM[1]	Fats g kg DM[1]	ME MJ kg DM[1]
Boot stage	131	245	463	39	11.2
Head emergence	99	300	554	28	10.1
Milk stage	79	320	624	26	9.2

KEY: NDF = Neutral detergent fibre. ME = Metabolizable energy
SOURCE: Todorov, 1995.

TABLE 11.4
Changes in chemical composition during the growing season of oats

Weeks and maturity stage	DM %	CP g kg DM[1]	CF g kg DM[1]	NDF g kg DM[1]	Fat g kg DM[1]	Ash g kg DM[1]	DMD %
1. 20-cm high plants	18.2	253	145	342	74	127	84.1
2.	21.8	223	165	399	65	94	81.5
3. Booting	15.7	208	205	442	57	94	75.2
4.	16.2	200	218	476	50	101	71.8
5. Emergence	20.6	146	272	588	38	93	58.6
6.	24.9	104	273	634	37	85	55.3
7. Milk	33.5	118	223	583	45	77	56.8
8.	42.8	118	220	564	38	72	55.3
9. Dough	53.7	125	209	545	39	75	57.2

KEY: DM = dry matter. CP = Crude protein. CF = Crude fibre. NDF = Neutral detergent fibre. DMD = Digestibility of dry matter in pepsin-cellulase.

with successful ensiling of oats, increases until the milk stage and then falls, as for most cereal crops. That decrease is related to conversion of WSC into grain starch and β-glucanes, and the low WSC content in the whole plant militates against successful silage fermentation. According to Demarquilly (1970), the content of WSC is 9.7 percent until the beginning of grain formation and decrease to 3.3 percent by the beginning of the dough stage. During this time, the starch content increases from 0.6 percent to 16.3 percent.

Digestibility

Many studies on oat nutritive value, as well as of other whole-crop cereals, were carried out in the 1960s (Nehring and Beyer, 1965, 1966; Demarquilly, 1970). It is difficult to find newer data on oats forage for ruminants, because interest has dwindled: the low nutritive value and low yield of oats renders it a less attractive forage crop than maize or ryegrass, so interest in it on the part of farmers and researchers decreases constantly. Due to the higher proportion of grain in the total mass, wheat and barley have a higher digestibility than oats. Their dry matter digestibility remains relatively constant, at about 60 percent, from mid-June until harvest. In contrast, oat digestibility decreases during the same period, from a level similar to that of barley, about 60 percent, down to 50–55 percent (Ingram, 1990).

According to Bulgarian studies, oat digestibility decreases continuously during the period from early vegetation to the milk stage, but increases slightly in early full ripeness (Table 11.4). This increase late in the growing season is probably

due to the increased proportion of grain in the total mass. During that period, the stem : leaf : grain ratio was 39 : 35 : 26. The increasing proportion of the grain, the digestibility of which is high and constant, compensated for the decreased digestibility of the other parts of plant, in particular the stems (Demarquilly, 1970). According to the data of Bozinova and Hristozov (1979), dried oats had the highest digestibility at milk stage and lowest at dough stage. They also mentioned that the digestibility of spring oats is higher than that of winter oats at the same maturity stage.

Intake

Intake is a relatively new parameter, which has been included recently in the system of estimation of nutritive value of forages, so it is difficult to find much data on oats. According to Demarquilly (1970), dry matter intake measured as DM ingested per kilogram of metabolic weight for wethers, decreases rapidly down to 45 g kg^{-1} W$^{0.75}$ at the start of grain formation. Thereafter there is a slight increase until the dough stage. More complete data on the intake of oats as whole-crop may be found in the tables of INRA (1988), France. According to them, oat intake is highest at the start of booting (80 g DM kg^{-1} W$^{0.75}$), decreases until flowering (47 g DM kg^{-1} W$^{0.75}$) and then slightly increases as the grain fills and is greater in proportion. Oat intake is similar to that of wheat and barley, but higher than that of rye and triticale.

Yield

The yield of oats increases and reaches a maximum under Bulgarian conditions in the second half of June and until the early dough stage. According to studies carried out in France (Demarquilly, 1970), dry matter yield per unit area quickly increases up to the milk stage and then more slowly from milk to dough stage, when it reaches a maximum value of 10.6 t ha^{-1}. Postiglione and Basso (1986), in a hilly area of southern Italy, obtained a higher yield from barley grown as a pure crop (7.7–8.9 t DM ha^{-1}) than from an oat+vetch mixture.

In Spain, it has been widely recommended to introduce mixtures of annuals with cereals, with the aim of increasing animal production. Under the conditions of central Spain, the yield of a mixture of oat+*Vicia sativa* under rainfed conditions was 6.7–6.4 t DM ha^{-1} and oat+*Vicia villosa* yielded 6.3–7.5 t DM ha^{-1} (Caballero and Goicoechea, 1986). In Portugal, oats grown in pure stand or in mixture with vetch gave higher yields compared with triticale (Trindade and Moreira, 1987).

Kertikov (2000) reported that the highest yield of dry matter and protein was obtained from a mixture of vetch and oats at 3 : 1 ratio and fertilizing with N:P:K at 90:50:40 kg ha^{-1}. The yield was 9 to 13 t DM ha^{-1} depending on the fertilizer rates, of which oat contributed 6–7 t DM ha^{-1}. The same author (Kertikov, 1999) announced a 15–21 percent higher grain yield from spring peas when using oats as a supporting crop to reduce both pea lodging and harvesting losses.

According to Tetlow (1992), dry matter yields of winter cultivars of oats between the end of May and the end of July reached a maximum of approximately 12 t DM ha^{-1} at the end of July, at a mean DM content of 43 percent. Spring varieties, harvested from mid-June to mid-August, had maximum yield of

10–12 t DM ha^{-1}, at a mean DM of 44 percent. The same author drew attention to the newer cultivars of oats, which gave maximum yields of about 15 t DM ha^{-1} in mid-June when grown on plots.

In some regions of the Russian Federation, such as the Non-chernozem zone or West Siberia, where soil and climatic conditions are not so suitable as elsewhere in Europe (sum of positive temperatures during the growing season is 2236°C days with average precipitation of 235 mm, while total annual precipitation is 414 mm), the yield of mixtures of oats with peas or vetch is higher than from pure stands, but far below the averages for Europe (Kuvshinova, Arharova and Rozanskaja, 1987; Novoselov, Rudoman and Lobanov, 1988; Dverina, 1989).

Regarding oat yield in Europe, there is a trend to increase from the south to north, which is related to the more favourable climate and rainfall during the oat growing season. On the basis of the changes in oat composition, digestibility, intake and yield during the growing season, earlier cutting and harvesting decrease the yield, but increase the quality of forage, both digestibility and intake, and improve the possibility for making a higher quality silage.

Use of whole-crop oats

Oats is a suitable forage crop for grazing, silage or making hay, and is often used as an additional forage to ensure the forage quantity for the farm, as well as other annual cereals (wheat, barley or rye).

Grazing

Oats can be grazed when the plants are young and reach a height of 20–25 cm. During this period it has a high crude protein content, low cell wall fibre level and high digestibility. The inconvenience is that oats do not stand trampling, and grazing should be light, controlled and rationed using electric fencing. If lightly grazed, oats recover and a second grazing or harvest of hay, silage or grain can be produced. Oats are grazed in some Mediterranean countries with unfavourable conditions, dry climate and insufficient rainfall for development of grasslands, but a mild winter. Greece is a country with typical Mediterranean climate and insufficient rainfall in summer, and oat grazing is a good alternative. Oats are an additional source for grazing, as well as for hay (Table 11.2). Light grazing is done in other countries with a mild winter, such as Portugal and Spain. On areas sown in October–November, the grazing is in January–February and then they are harvested for grain, hay or silage.

Silage

Whole-crop oats is most often used as silage or haylage for feeding ruminants in central and north European countries. In UK, the annual quantity of silage from wheat, barley and oats is estimated to be about 200 000 t of dry matter (Wilkins and Kirilov, 2003). Successful ensiling depends on the quantity of fermentable water-soluble carbohydrates (WSC) and the DM content. Good WSC content, in particular before grain formation, allows the making of good silage from oats, especially in combination with preliminary wilting. In the literature, there are often descriptions of mediocre oat silages, made at the dough stage, when the aerobic stability is lower. At the dough stage, when the yield is close to

maximum, the WSC content is lower, but in combination with higher DM content it ensures good silage fermentation. Oat stems are hard and hollow, which impedes compressing of the mass and the creation of anaerobic conditions for successful ensiling. The hollow stems and high residual WSC create additional problems after opening silos, because air enters more deeply, provoking secondary fermentation and causing degradation of residual WSC and lactic acid.

In a comprehensive study on the use of whole-crop cereals, including oats, in the UK, Weller (1992) found that harvesting for silage was between the cheesy dough and hard dough stages, and the crops were mown at between 7.5 and 15 cm above soil level.

Le Gall and Pflimlin (1997) noted that, taking account of ensiling losses, harvesting costs and the low energy value of silage from whole-crop cereals in France, the price of a kilogram of silage dry matter was equivalent to the price of a kilogram of cereal grain, which had 40 percent higher energy value. So ensiling whole-crop cereals is not so attractive, even in years of forage deficiency.

Through mowing higher, the energy value of oat silage can be increased at the expense of yield. Increasing mowing height from 10 cm above the ground to 15 cm below the ears, Demarquilly, Paquiet and Andrieu (1969) achieved an increase in digestibility of 10 percentage points. The negative effect on yield can be decreased if grazing follows harvesting for silage. Increase in nutritive value may be achieved by earlier harvesting for silage. Earlier mowing decreases dry matter yield, but increases quality and intake of forage and clears the land for the next crop.

When determining the optimum time of harvest and ensiling of oats or other whole-crop cereals, there is a compromise between high yield, which increases until hard dough stage, and obtaining silage of higher nutritive value, which decreases continuously during the growing season. In cereal silage made at the hard dough stage, the grain is hard and part passes almost intact through the cattle's gut. Part of the energy is lost and silage making from cereals at the late stage is not recommended, in particular if destined for cattle.

Harvesting oats and other cereals at the milk to soft dough stage is recommended (Staples, 1989; Bozinova and Hristozov, 1979); the yield is lower, but nutrient concentration in dry matter is higher. At a low dry matter content level, as occurs frequently in some regions of the Russian Federation, wilting the mass before chopping is recommended. The aim is to increase the dry matter content up to 35 percent to improve fermentation, to avoid juice out-flow and nutrient loss. Undesirable butyric acid bacteria develop poorly at moisture contents below 70 percent and their development ceases below 65 percent.

The length of chopping is an important factor for the success of ensiling. A theoretical chop length of 10–20 mm is considered optimal (Bozinova and Hristozov, 1979). Finely chopped silage is ingested in greater quantity than long. Fine chopping can be done after opening the silo, just before feeding the silage to the animals. In trials, supplementary chopping of silage from a pea-cereal mixture increased the proportion of particles below 20 mm from 22 percent to 67–68 percent, and the dry matter intake for wethers increased by

75 percent compared with the same silage, but long chopped (Kirilov and Sachanski, 1989). The positive effect of the fine chopping of silage on the intake is greater for sheep than for cattle.

Fine chopping facilitates silage packing and mechanized distribution, improves fermentation processes and intake by the animal. The finely chopped mass is easier to pack in the silo and that is important since the hollow stems of oats retain residual air in the silage, which leads to additional WSC loss. When silage is not well packed, on opening the silo air penetrates deeper into the silage and it is necessary to take a greater quantity of silage every day to refresh the open surface. Poorly packed silage has low stability when exposed to air.

Urea, enzymes and inoculants are used to improve silage from good quality whole-crop cereals. Urea increases the nitrogen content and exerts no substantial influence on fermentation. Silage with urea has good aerobic stability. Enzymes added to the silage degrade hemicellulose, cellulose and starch into WSC, which becomes accessible to micro-organisms and facilitate the fermentation processes. Inoculant adds strains of lactic acid bacteria to direct fermentation and use WSC in priority production of lactic acid and quick decrease in silage pH. Sometimes this is related to addition of molasses and other carbohydrate additives. The inoculant treatment of oat silage increases dry matter intake and milk production of dairy cows (Meeske *et al.*, 2000).

Hay

Oats are occasionally used for haymaking in countries with suitable conditions of enough sun and warmth during the haymaking period. Oats are cut for hay before full grain formation in order to avoid grain loss during manipulation, tedding and baling. Up to that stage, oats have better digestibility and nutritive value than later. Mowing machines with crimping rollers to permit faster moisture release are used for faster drying and to decrease the time the mown crop is in the field, thus reducing the risk of rain and wetting and consequent quality loss. Swath tedding contributes to even drying and decreases the time necessary for drying. Oats are also suitable for hand cutting with a scythe and for manual haymaking.

In Bulgaria, some cooperatives and private farmers grow oats as a pure stand or in mixture with vetch and peas and make hay for household livestock. Households pay for this service to cooperatives and keep the hay for the winter (Figures 11.4 and 11.5). This practice is convenient for the small-scale stockholder "farmers" having one or two cows and 5–6 sheep or goats.

Straw

Oat straw and chaff are softer and finer than the straw of the other white-straw cereals and have a higher nutritive value (Table 11.5). It is a favourite by-product for feeding ruminants or for bedding. In Bulgaria, oat straw and other cereal by-products are very often used as forage in winter domestically (Figure 11.6).

CONCLUSION AND PROSPECTS

Oats as grain and whole-crop have a lower nutritive value than maize and some cereals, and cannot meet the energy requirements of high-yielding animals. This is one of the main causes for the decrease in oat areas on a global scale.

Figure 11.4a
Bales of oat hay

Figure 11.4b
Close-up view of baled oat hay

Figure 11.5
Oat hay stacked for winter feed

TABLE 11.5
Composition and nutritive value of straw

Straw	CP (g kg DM⁻¹)	CF (g kg DM⁻¹)	NDF (g kg DM⁻¹)	Fat (g kg DM⁻¹)	ME (MJ kg DM⁻¹)
Wheat	37	440	898	17	6.38
Barley	42	433	823	18	6.66
Rye	33	480	902	17	6.26
Oats	41	428	740	20	6.82

KEY: CP = crude protein. CF = crude fibre. NDF = Neutral detergent fibre. ME = Metabolizable energy.
SOURCE: Todorov, 1995.

However, the high content of water-soluble carbohydrate in the whole plant means oats make good silage and can thus supplement the forage needs of the farm. Grazing or harvesting at an earlier stage can compensate for the low energy concentration and low nutritive value of oats. At that stage, the protein content is high and fibre is low, so the nutritive value is high. The use of oats for forage is a sign of extensive farming and forage production, but is a good alternative for many farmers in Europe.

Although the oat area is decreasing, it seems that the interest in it as an alternative forage will remain. In unfavourable years, forage oats, with their longer growing season, provide farmers with the possibility of obtaining forage by harvesting areas destined for grain.

Figure 11.6
Forages stored for the winter in Bulgaria (lucerne hay, oat straw, maize stover and pumpkins)

In the dry Mediterranean zone, where extensive pastoral systems with sheep, goats and cattle predominate, oats will continue to have a role as a substitute for ryegrass for grazing and for hay. In this region, there is a trend for the area sown to forage oats to remain stable, or even to expand.

Against the background of global warming and potential drought in southeastern Europe, many farmers and small stockholders will rely on oats in pure stand or in a mixture with peas or vetch for silage and hay, using the winter-spring soil moisture. In other regions of Europe, the use of oats as a nurse crop at sward establishment will persist.

In parts of the Russian Federation, oats will remain the preferred cereal companion crop in mixtures with legumes for production of protein for ruminants. Earlier harvesting of cereals for silage or hay makes possible double cropping of the land, which gives additional forage and has also a positive ecological effect, as the land remains covered with vegetation for longer during the year.

The prognoses for use of whole-crop oats as forage in countries with intensive livestock farming and forage cropping zones are not optimistic. Intensive forage production in the countries of northwestern Europe is based on silage maize and grassland, dominated by ryegrass, for

which the soil and climatic conditions are favourable. In these countries, there is no trend to increased forage oat area, except on organic farms in crop rotations giving a "health crop rotation" for both diseases and weeds. Sometimes in circumstances when a low yield is expected, oats grown for grain might be profitably harvested as silage or hay. In all other cases, whole-crop oats remain a good alternative to additional forage production.

Chapter XII
Oat diseases and their control

José Antônio Martinelli

SUMMARY

Fodder oats are widely used in the world, particularly in subtropical and temperate zones. As a cereal, oat is subject to attack by many disease-causing micro-organisms, some of them causing severe damages. This chapter reviews most of the main oat diseases, with special emphasis on oats destined for fodder.

INTRODUCTION

Oats are an important fodder and grain crop in countries of the southern cone of South America. Approximately 600 000 ha of oats are grown for grain in Argentina, Uruguay and southern Brazil, but more than 4 000 000 ha are grown for fodder (Matzembacher, 1999; Rebuffo, 1997; Trombetta, 1997), although in Brazil much of the fodder oat is *Avena strigosa* rather than *A. sativa*. In the subtropical to temperate climate of this region, oats are grown in the winter and used as a winter cover crop, as food for both livestock and humans, and as raw material for industrial use. It is the third most important winter crop in southern Brazil (Leonard and Martinelli, 2004).

As in South America, fodder oats are important in other large areas of the world, like Australia, North America and Europe, and in all these regions oat diseases are of major concern in crop management. Some diseases are caused by highly specialized, biotrophic pathogens, such as the rusts and powdery mildews, whose mechanisms of spread are very efficient, making some crop management, such as rotation, inefficient for their control. Other diseases are caused by less specialized pathogens, those called hemibiotrophic, whose biological life cycles differ considerably from the first group. For these, simple practices, such as seed dressing and crop rotation, can reduce the initial inoculum, so that the disease does not reach economic threshold levels. The viruses, especially Barley Yellow Dwarf Virus (BYDV), form a third group of pathogens, whose occurrence is associated with the pattern of distribution of their vectors, the aphids, which constitute another phytosanitary problem.

For evolutionary reasons, most of the pathogens that attack oats have a close relationship with the plant. So, in most areas where the environment suits the crop, it also favours the occurrence of the diseases that these pathogens cause. Some pathogens, however, are less adapted to the species or less robust in these environment, and they cause less serious, or sporadic, diseases.

Many diseases cause either serious direct damage, mainly by reduction of the fodder yield, or indirect damage, by compromising the quality of the product. Among those causing severe direct dam-

Figure 12.1
Pustules of Crown rust on oat leaves caused by* Puccinia coronata *f.sp. avenae.

age are crown and stem rusts, leaf blotch caused by *Pyrenophora* spp. and *Septoria* spp., and BYDV. Other diseases, such as scab and ergot, can produce toxins in the grains and make them unsuitable for consumption by either animals or humans.

The aim of this chapter is to present the main diseases of fodder oats in the main production areas of the world. Emphasis is put on the characteristics of the diseases, their epidemiological aspects, their management and the commonest measures of control.

MAIN OAT DISEASES

Crown rust

Crown rust is the most harmful disease that affects oats and it is distributed worldwide, having been observed in all areas where these crops are grown (Simons, 1985). Crown rust is one of the most important oat diseases in Brazil, Argentina and Uruguay. Grain yields are negatively correlated with crown rust severity (Chaves *et al.*, 2002) and may be reduced by as much as 50 percent in susceptible cultivars (Martinelli, Federizzi and Benedetti, 1994). It is caused by *Puccinia coronata* f.sp. *avenae* (Figure 12.1), a heteroecious macrocyclic rust (Agrios, 1997).

One of the particularities of this disease is its capacity to attack several plant species. The uredial and telial phases occur on oats and other grasses, including all species of oats (*Avena* spp.), *Secale cereale*,

Hordeum vulgare, *Lolium* spp., *Festuca* spp. and *Bromus inermis*, among others; the spermagonial and aecial phases occur on *Rhamnus* bushes, the alternate host (Browning, 1973; Harder and Haber, 1992).

Infection by the pathogen induces several structural, biochemical and physiological changes in its host. The more profound changes are brought about by intracellular invasion by the fungus and the formation of haustoria, but in the early stages of infection there are no direct physiological effects of the intercellular hyphae on the protoplasts of the host (Harder and Haber, 1992).

Alterations in photosynthesis occur during the development of the infection and, soon after the inoculation, a decrease in gaseous exchanges is observed in the whole leaf. The infected areas, initially discrete, expand with the progress of the infection and symptoms of the disease appear about five days after inoculation, characterized by yellow spots, associated with the presence of mycelium of the fungus within the tissues. At this stage, photosynthesis is slightly reduced in the infected areas, but not in those parts of the leaf without infection, where the process shows levels similar to healthy parts. During sporulation, typically eight days after inoculation, there is a reduction in the rate of photosynthesis throughout the whole leaf, although this reduction is more conspicuous in areas invaded by the fungus. Eleven days after inoculation, "green islands" are formed around those areas of the leaf associated with the mycelium of the fungus and photosynthesis is drastically inhibited in the whole leaf. In areas not infected by the mycelium of the pathogen, photosynthesis is very low, indicating that even in these areas the photosynthetic apparatus is seriously damaged. In the green islands of the leaves, photosynthesis is low, but detectable, indicating that some photosynthetic processes are still occurring (Scholes and Rolfe, 1996).

Disease symptoms appear as yellow pustules containing masses of urediospores, which are exposed after the rupture of the epidermis. These lesions are circular or oblong and occur in both surfaces of the foliar sheet and can reach other green parts of the plant, when the epidemic becomes more severe. After some weeks, the borders of the uredopustules can turn black, with teliospore formation. When the infected plants reach maturity, production of urediospores ceases and they are then replaced by teliospores (Browning, 1973; Simons, 1985; Harder and Haber, 1992).

Primary infections are caused by urediospores or aeciospores. In areas of subtropical and temperate climate, where oats are grown in winter, urediospores from volunteer plants that survive the summer are usually responsible for the primary infections of plants sown in autumn. In Europe and in North America, the alternate host, *Rhamnus* spp., is an important source of inoculum for the oats, since it contributes through sexual recombination to the great variability observed in the pathogen population. The teliospores on infected straw from the previous summer germinate in spring, producing basidiospores, which in turn infect young leaves of *Rhamnus*. These infections produce aecidia from which aeciospores arise and then infect the oats. In South America, teliospores of *Puccinia coronata* have no known survival function

(Martinelli, 2000). The primary source of inoculum to infect oats in autumn comes from urediniospores produced on volunteer plants that survive the summer on the edges of fields of summer crops such as soybean, in fence lines and along roadsides. Prevailing wind patterns annually distribute urediniospores of *Puccinia coronata* in a cyclical pattern throughout the oat growing regions of Brazil, Argentina and Uruguay as a shared epidemiological system. Epidemics typically start early; sometimes while oats are still at the tillering stage. *A. strigosa* is less susceptible than *A. sativa*, but rust severities of 5–10 percent are common during the growing season (Leonard and Martinelli, 2004).

Urediospores and aeciospores of *Puccinia coronata* f.sp. *avenae* are spread by the wind and can travel long distances. Their germination needs free water on the leaf surface and infection occurs through the stomata. These two processes are favoured by temperatures between 10 and 25°C. Temperatures above 30°C inhibit the infection process (Simons, 1985).

Stem rust

The causal agent is *Puccinia graminis* Pers. f.sp. *avenae* Eriks. and Henn., which attacks all species of oats, including wild oats (Wallwork, 1992). Stem rust is a widespread disease of oats, occurring almost everywhere they are grown (Zillinsky, 1983). In Canada, it occurs almost every year in some provinces, including in Ontario, Quebec, Manitoba and eastern Saskatchewan, causing severe crop losses (Martens, Seaman and Atkinson, 1985). In Australia, it can be devastating, causing crop losses up to 100 percent (Wallwork, 1992). In South America, stem rust epidemics are typically at the end of the crop season, from booting stage onwards, when the temperature is warmer. In Argentina, where *A. sativa* is used as fodder, it is particularly serious because their cycle is longer than that in Brazil, where the importance of the disease has diminished because oats are harvested earlier (personal observation of the author).

Disease symptoms most commonly appear on the stems and leaf sheaths, but leaf blades and spikes may also become infected. Urediospores develop in pustules (uredia) that rupture the epidermis and expose masses of reddish-brown spores. The pustules are larger than those of crown rust, oval or elongated, with loose or torn epidermal tissue along their margins. They may appear on both surfaces of the leaf. They continue to be produced until the plants approach maturity. After that, teliospores develop, either in the same uredia or in other fruiting structures called telia.

Epidemics are more likely when weather is warm (15–30°C) and conditions moist (Wallwork, 1992). Stem rust develops its sexual stage on *Berberis vulgaris* L. In North America, the disease is usually not as widespread as crown rust, probably because the alternate host is less common than *Rhamnus cathartica* (Harder and Haber, 1992). In the absence of the alternate host (South America and Australia) its distribution and epidemiology follows the same pattern as that of crown rust (Leonard and Martinelli, 2004).

Main control measures for rusts

Attempts to breed oat cultivars resistant to crown rust have been frustrated in most countries by the rapid appearance of

new virulent races of *Puccinia coronata*, often within a few years of the release of cultivars, with new types of race-specific resistance. According to Federizzi and Stuthman (1998), the rapid breakdown of resistance observed in South America is due to the large population of *P. coronata* maintained in the uredinial stage throughout the year and the large numbers of mutations to virulence that occur annually in the pathogen population. Although a large number of genes for race-specific resistance to crown rust are available to oat breeders, information on occurrence of virulence to these genes in the South American populations of *P. coronata* has been largely lacking. Recently, efforts have been made to search for a more stable, quantitative, non-specific resistance to crown rust, such as the one provided by the *A. sativa* genotype MN841801 from the University of Minnesota breeding programme. In Brazil, Chaves, Martinelli and Frederizzi (2004a, b) were able to identify a number of promising genotypes as sources of quantitative resistance.

There is a much more limited reservoir of resistance to stem rust, but known genes can provide effective and long-term resistance when used in appropriate combinations. In Argentina, the only oat variety currently in use that is resistant to stem rust is the genotype UFRGS-16, bred by the oat breeding programme of the Federal University of Rio Grande do Sul State.

Eradication of the alternate *Rhamnus* and *Berberis* hosts has been an important factor in reducing crown and stem rust epidemics in areas where these hosts play a major role as sources of inoculum and genetic variability for the pathogen. *Berberis* now plays a minor role in most of North America. *Rhamnus* is difficult to control and extensive infestations still remain, particularly in Ontario, Canada (Harder and Haber, 1992).

Escape is another important factor in reducing damage by the rusts. This can be achieved by advancing the planting dates or by using early maturing cultivars. Typically, no chemical control is used for crown or stem rusts on oats destined for pasture.

Pyrenophora leaf blotch

The causal agent of leaf blotch and darkening on oat grains is the fungus *Pyrenophora chaetomioides* Speg. Briosi and Cavara, cited by Dennis (1935), who made the first report of its imperfect stage, *Drechslera avenae*, in 1889, in the Pavia region of Italy. Initially it was named as *Helminthosporium teres* Sacc. form *avenae-sativae*. The name *Pyrenophora chaetomioides* Speg., the stage used for the description of the ascocarp, has precedence over the name *Pyrenophora avenae* Ito and Kurib. (1930), according to Sivanezan (1987).

Pyrenophora leaf blotch (Figure 12.2) has been reported from most areas of the world where oats are grown. In 1974, there were reports of epidemics of leaf blotch on oats in Germany and the south of the USA, where it appeared as the most severe disease after crown rust, with damage estimated at around 30–40 percent (Gough and McDaniel, 1974). It is also common as a seed-borne pathogen in Sweden and in Finland, where losses of up to 10 percent can occur; in India the disease has been reported as widespread from the seedling stage till plant maturity (Harder and Haber, 1992). In

Figure 12.2
Symptoms of Leaf blotch and black nodes on oat, caused by Pyrenophora chaetomioides

Brazil, *P. chaetomioides* is considered the main pathogen associated with oat seeds (Blum, 1997), although high severities of leaf spots are less common. So far, there is no evidence that this fungus produces toxins on either leaves or grains that could compromise the use of infected oats as fodder.

The most commonly observed symptoms of leaf blotch of oats appear on the leaves and, under favourable conditions for the disease, they can reach the sheaths and appear soon after their emergence (Ivanoff, 1963). Those symptoms were described by Ellis in 1971 as small spots initially (1–3 × 1–2 mm), with a white centre surrounded by a brown-reddish halo that later coalesce and expand, forming small longitudinal stripes. In conditions in the south of Brazil, the leaf blotches are prolonged longitudinally, with dark coloration, eventually becoming olive and with a greyish centre.

Another symptom, called black-stem or stem-break, is characterized by darkening of the nodes and by the ease with which stems break. It was initially described by Luke, Wallace and Chapman (1957) and Jones and Clifford (1983), and observed, in Brazil, by Rocha (1996). These symptoms start appearing from lesions on the leaf sheaths that are in direct contact with the nodes, become dark and make a more severe infection

Figure 12.3
Symptoms of oat kernel darkening produced by the mycelium of Pyrenophora chaetomioides, *the causal agent of Leaf blotch on oat, growing superficially*

process. When infection is more severe, a mycelial mass of fungus can be seen in the stem cavity, and the stem breaks easily between the third and fourth internodes. These authors emphasize that this black-stem symptom resembles one described for *Septoria avenae* Frank (Luke, Wallace and Chapman, 1957).

Besides the symptoms described above, other symptoms can be associated with *P. chaetomioides*, such as the "spikelet-drop" described by Ivanoff (1963), and spots on stems, which can be elongated and narrow or expand themselves irregularly (Harder and Haber, 1992).

Symptoms on seeds were first described by Blum (1997). Later Bocchese *et al.* (2001) described symptoms of widespread darkening on the surface of the grain (Figure 12.3), on the three superficial layers of the caryopsis, whose intensity varied from yellow-brown to black, depending on the density of the mycelium and its local enzymatic activity.

On infected crop residues of the host, *P. chaetomioides* develops structures called pseudothecia, which have often been found on residues of oat crops on farms in the south of Brazil (Martinelli *et al.*, 2003). However, the sexual stage of the fungus (*P. chaetomioides*) is rarely mentioned in the literature and is considered to be of minor importance as an inoculum source. The asexual form of *P. chaetomioides* produces conidia on dead straw, which are the main source of inoculum for the forming grains and for subsequent oat crops, since the fungus is not a natural inhabitant of the soil (Shaner, 1981) and it does not survive as resting spores on the soil nor does it have resistant structures (Reis, 1987).

Seeds, in contrast, guarantee the survival of the pathogen for long periods in the absence of other sources of inoculum. According to Machcck and Wallace (1952), recovery of the fungus was possible in 10 percent of oat seeds stored for 10 years, which confirms the importance of infection by the mycelium. In oat seeds stored in a laboratory, Sheridan and Tan (1973) observed that the mycelium of *P. chaetomioides* stayed viable for seven years. The fungus survives in stored, infected seeds and stays dormant due to the low humidity of the seed, usually from 12 to 13 percent (Reis, 1988).

Shaner (1981) also reported that seeds could be sources of primary inoculum in areas where crop rotation is practiced. The amount of this inoculum will depend on the intensity and on the environmental conditions during the production of the seeds. After sowing, upon germination and emergence of oat seedlings, the mycelium recovers its activity, attacking the first leaf on which the fungus can produce some spores (Reis, 1987). However, the greatest conidia production happens on dead tissues of the basal leaves, forming the secondary inoculum, which is then disseminated to other, more distant, parts of the plant, especially panicles and their forming seeds (Rosa *et al.*, 2003), thus completing its biological cycle. According to Blum (1997), there are no reports of secondary hosts that this fungus can infect to produce inoculum.

Therefore, undecomposed, infected crop residues of infected oats, as well as volunteer plants are important sources of primary inocula for *P. chaetomioides*. This is accentuated in areas of monoculture or no-till planting, due to reintroduction of the pathogen to the recently established area (Shaner, 1981; Reis, 1987, 1988).

The spread of *P. chaetomioides* mainly occurs through infected seed (the main source of inoculum) in areas where crop rotation is used. Spread through conidia and ascospores occurs over short distances by wind or through water splashes (Shaner, 1981).

Infection of the seed happens during flowering of the spikelet. Conidia of *P. chaetomioides* germinate and penetrate the pericarp of the maturing grain. Some works demonstrate that the milk stage is most susceptible to infection and that foliar and seed susceptibility are not connected (Turner and Millard, 1931; Schilder and Bergstrom, 1994). Its viability lasts for a long time (Turner and Millard, 1931).

One of the most desirable methods of control is through genetic resistance. Surveys of this disease exist around the world, such as the European Oat Disease Nursery, which monitors disease incidence and records the effect of the sources of resistance for all important diseases of oats in 19 European countries, as well as Israel and Morocco. This programme has reference sources of resistance to *P. chaetomioides*, such as those in the oat genotypes Maldwyn, IL86-4189 and IL85-6467 (Harder and Haber, 1992; Frank and Christ, 1988; Sabesta *et al.*, 1996).

In Brazil, the Federal University of Rio Grande do Sul has been involved in a research programme to select resistant genotypes, characterize their expression and inheritance, and transfer resistance to new cultivars. Recent data (Bocchese *et al.*, 2001) suggest that the resistance that operates in these genotypes is of a quantitative type.

Crop management aiming to reduce the incidence or severity of this disease

is based on the reduction of the inoculum at primary sites, which are crop residues of oats, infected volunteer plants and infected seeds (Reis and Casa, 1998). In areas where the inoculum is present on dead matter on the soil surface, crop rotation using non-host species has been the preferred control measure, as well as other practices that eliminate crop residues on the surface of the soil (Shaner, 1981; Reis, 1987; Haber and Hader, 1992).

Control through biological methods must be effective at the rhizosphere level. Inoculation of seeds with antagonistic organisms is more effective in protected situations. In the field, behaviour against the pathogen will depend on its interaction with soil micro-organisms and also with the predominant environment (Maude, 1998). In 1994, Ronquist reported treating oat seeds with isolates of *Pseudomonas chloraphis*, a common bacterium of the rhizosphere, which gave positive results in the control of *Pyrenophora chaetomioides.*

Fungicidal seed dressing has been one of the measures most used to control *P. chaetomioides* (Boewe, 1960; Tempe, 1964; Jones and Clifford, 1983; Hader and Haber, 1992), but treatment with modern fungicides has not been eradicative (Blum, 1997) due to the high level of incidence of the pathogen in the seeds, and, as a consequence, an inability to prevent the spread of the disease to the aerial part of plants. Reis and Soares (1995) tested fungicides and doses to be recommended for seed treatment, and obtained a maximum control of only 30 percent for *P. chaetomioides*, using a thiram+carboxim mixture. This shows the difficulty of eradicating the fungus by this method.

Scab

Scab or Fusarium head blight (FHB) is caused mainly by *Fusarium graminearum* (teleomorph = *Gibberella zeae* Schwabe Petch.) (Schoroeder and Christensen, 1963). Other species, such as *Fusarium culmorum, F. avenaceum, F. moniliforme, F. oxysporum, F. poae* and *Microdochium nivale*, can also constitute a complex with the disease, although they are usually less important than *F. graminearum* (Warren and Kommedahl, 1973; Wiese, 1987). Isolates of *F. graminearum* differ in virulence and there is no evidence of the existence of stable races of the pathogen (Bai, Shaner and Ohm, 1991; Mesterhazy, 1987).

Disease caused by *F. graminearum* is common in areas of humid climate, such as in South America. Its occurrence has increased in recent years, reaching epidemic levels in several countries, including Argentina, Brazil, Canada, Mexico, Uruguay and USA (Reis, Panisson and Boller, 2002).

The causal agent of scab passes part of its life cycle as a saprophyte, decomposing the organic matter of its hosts, which include wheat, barley, rye, triticale, ryegrass, maize and oats, which remain on the surface of the soil. Direct seed drilling or minimum tillage has contributed to the increase of inoculum and the intensity of the disease in the main areas of the world where these cereals are grown. As a consequence, particularly from the mid-1990s, scab emerged as an important pathogen on other species as well, previously considered as non-hosts. For example, in 1999, Martinelli, Mundstock and Federizi reported for the first time the occurrence of an epidemic of *F. graminearum* on oats in the south of Brazil, although the damage was not precisely estimated at the time.

Figure 12.4
***Symptoms of Oat scab (Fusarium head blight) on crown of oats, caused by the fungus* Fusarium graminearum**

For the other cereals, damage caused by the disease can be direct, related to yield losses, or indirect, related to the contamination of grain with mycotoxins produced by the fungus (Sutton, 1982; Parry, Jenkinson and McLeod, 1995; Jones and Mirocha, 1999). In South America, the greatest damage recorded in wheat was 14 percent, with an average of 5.4 percent from 1984 to 1994 (Reis *et al.*, 1996). In the epidemic in 2000, the incidence of scab on wheat was over 70 percent, with yield losses of 14 percent (Panisson, Reis and Boller, 2003).

The characteristic symptoms of scab in oats (Figure 12.4) are discoloured spikelets, pale or whitish in colour, which contrast with normal green healthy panicles. In favourable conditions for the disease, salmon-pink signs of the pathogen are easily observed on infected spikelets, as well as at the base and edges of the glumes. In infected panicles, the grains are light, wrinkled and wilted, with a white-rosy or pale-brown colour.

Warm and humid environmental conditions, such as temperatures between 20 and 25°C and atmospheric relative humidity higher than 90 percent, or rain for at least 48 hours, favour the disease. Initial inoculum comes from crop remains of several hosts, where the pathogen can survive. The ascospores are disseminated by the wind to the anthers, which are their

preferred sites of infection (Reis, Panisson and Boller, 2002).

Scab control is difficult due to the absence of resistance and lack of effective management practices that help reduce the inoculum. Although spores are present on seeds, these are not the main source of inoculum for the establishment of the disease. In addition, none of the fungicides available today are effective as seed dressing, and are not recommended for control of the disease.

Smut

Smut diseases, caused by *Ustilago* spp., which occur worldwide, have been among the most destructive of oat diseases. Until the 1940s, annual losses due to loose smut across the USA were estimated at 3 to 5 percent, and in western Canada losses of 10 to 25 percent were common, with some fields showing 75 percent smutted heads. Despite the use of resistant cultivars and chemical control to reduce disease levels, loose smut occurs most years in many areas. Until a few decades ago, considerable damage occurred in parts of USSR, and an increase in loose smut has been noted in New Zealand (Harder and Haber, 1992). In South America, smut is of minor importance in reducing yields. Its frequency is very low since most fungicides used to control other seed-borne pathogens also control smuts. The disease does not produce any toxic compound, which makes its occurrence less worrying for farmers.

On oats, there are two forms of smut: loose, caused by *Ustilago avenae* (Pers.) Rostr., and covered, caused by *Ustilago kolleri* Wille (Wallwork, 1992). Infected plants may be somewhat shorter than healthy ones, but smut symptoms are mainly visible on the panicle. Infected panicles emerge at the same time as healthy ones and usually have a narrower and erect habit. Loose smut destroys seeds, hulls and glumes and replaces them with a powdery mass of dark brown spots. As the crops ripens, most of the spores are blown away or washed off by rain, leaving only a few spores and small, light-grey fragments of host tissue on the panicle. In covered smut, the somewhat compacted spores are enclosed in the remains of hulls and glumes, which turn a light grey towards maturity (Martens, Seaman and Atkinson, 1985).

Oat smuts are carried over from season to season as seed-borne spores. Those lodged under the hull are the most effective in causing new infection. When infected seed is sown, the spores germinate and the hyphae penetrate the very young seedling and invade the growing point. The fungus and host plant develop together until finally the smut destroys the flowers and replaces seeds and most of the glumes with spores. The spores of loose smut are easily dispersed by wind; if they land in healthy florets they complete the disease cycle. Covered smut re-infects in the same manner, but the spores are more often dispersed during grain harvest and handling (Martens, Seaman and Atkinson, 1985).

Under natural conditions, the amount of smut infection varies considerably from year to year, variation depending less on the amount of inoculum available than on the conditions prevailing at flowering or during germination. Spore release peaks to coincide with flowering (Mills, 1967), but cool, dull conditions at flowering may result in less opening of the florets, and hence less opportunity

for floral infection. Smut fungi tolerate relatively wide ranges of temperatures and humidity, but the amount of infection is strongly influenced by interactions of factors that affect germination and growth of both fungus and host. In general, infection occurs between 6 and 25°C, with an optimum of around 18 to 22°C, provided that soil moisture is relatively low. High soil temperature combined with high moisture is least favourable for infection (Harder and Haber, 1992).

Smut control is now relatively easy because either systemic fungicides (Martinelli, 1998; von Schmeling and Kulka, 1966) or breeding for resistance are effective since more varied sources of resistance have been found in breeding programmes (McKenzie *et al.*, 1981, 1984).

Barley Yellow Dwarf Virus (BYDV)

Since the mid-1980s, barley yellow dwarf has become increasingly widespread in the USA and is now of serious concern to oat and wheat producers. Outbreaks occasionally reach epidemic proportions, as occurred on wheat in 1987 and oats in 1988.

Barley yellow dwarf virus (BYDV) is a member of the luteovirus group. Luteoviruses are characterized by inducing "yellowing" symptoms and are restricted to phloem and thus not mechanically transmissible; they are persistently and specifically transmitted by aphids, and occur as about 25-nm isometric particles (Mathews, 1982). BYDV actually includes several related viruses, grouped into five strains based primarily on the specific aphid species able to transmit a particular strain. BYDV can be transmitted by 23 species of aphid and infects almost 100 species of annual and perennial grasses, including barley, maize, oats, rye and wheat (Watkins and Lane, 2004).

BYD is diagnosed (Figure 12.5) in the field by the presence of yellowish to reddish stunted plants grouped singly or in small patches among normal plants. Early infection of any of the cereals may result in severe stunting, excessive or reduced tillering, bright-yellowing or reddening of older leaves, delayed heading or ripening, increased sterility, and fewer and lighter kernels. In some oat cultivars, leaves become bronzed. This disease is not the only cause of red coloration in oats. Post-seedling infections are progressively less severe to the point where only the upper leaves, or the flag leaves, show discoloration. The leaves of plants infected with BYDV are shorter than normal and the flag leaf may be severely shortened. Leaves are often stiffer and more erect. Root systems are reduced and diseased plants are more easily pulled up than healthy ones (Wallwork, 1992; Watkins and Lane, 2004). On oats the first symptoms are yellowish-green spots or blotches near the tips of older leaves. Eventually these blotches enlarge and coalesce. Symptoms vary according to the variety, the virus strain, the growth stage of the plant at the time of infection, the general health of the plant, the temperature and other environmental factors. The main colour change is to shades of yellow, reddish-orange, reddish-brown, or purple (Martens, Seaman and Atkinson, 1985).

Stunted plants result from the failure of stem internodes to elongate. This leads to a "telescoped" plant where the leaves may unfurl before they have fully emerged from the sheath of the previous leaf. Infected plants are "dwarfs" and have

Figure 12.5
Symptoms of Barley Yellow Dwarf Virus (BYDV) on oats

lost their normal conformation. Even the panicle fails to emerge fully or properly. Patterns of BYD in a field may be seen either as random within the crop or as circular or angular patches, which reflect the pattern of movement of the aphid vectors or carriers. Many infected plants ripen prematurely, after which they may be invaded by sooty moulds, which give them a dirty appearance and may lower germination of harvested seed (Watkins and Lane, 2004).

Of the more than 20 aphid species that transmit BYDV, the most important are the oat bird-cherry aphid (*Rhopalosiphum padi*), maize leaf aphid (*Rhopalosiphum maidis*), English grain aphid (*Sitobion avenae*), and the greenbug (*Schizaphis graminum*). The rose grass aphid (*Metapolophium dirhodum*) is widespread in Europe but not in North America. The oat bird-cherry and the English grain aphids are the most important carriers of BYDV in oats.

BYDV overwinters in infected winter cereals and in wild and cultivated grasses. Perennial grasses such as bluegrass (*Poa pratensis* L.), cocksfoot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb) and little bluestem (*Andropogon scoparius* Mixch) may serve as reservoirs of the various strains of BYDV. Oats and barley are very susceptible to BYDV. Where these crops are sown late for soil cover, wind erosion control, for fodder, or are volunteers, they are often heavily infected and can be an important local source for migration of aphids and the virus into adjacent autumn sown wheat.

Aphids acquire BYDV by feeding on infected plants. It normally takes 24 to 48 hours of feeding to acquire the virus, but, once done, the aphid remains a carrier for life. Spread of BYDV depends entirely on aphid movement. One very active aphid feeding for short periods on different plants is a more important carrier than several stationary ones.

Damaging outbreaks of BYD are most likely at high light intensities and in cool,

moist seasons (near 15°C), which favour not only grass and cereal growth but also aphid reproduction and migration. Driving rain may spread aphids, but will also reduce their populations. BYDV is specialized in its relationship with aphid carriers and is not transmissible through seed, plant sap or other insects (Harder and Haber, 1992; Watkins and Lane, 2004).

The best control is based on varietal resistance or tolerance. Resistance or tolerance is available in barley and oats. The oat cultivars Bates, Hazel, Noble, Otee and Pierce are resistant to BYD; Don, Lang, Larry, Ogle, Starter and Steele are moderately resistant.

Late-planted spring oats in the North Hemisphere and early-planted oats in South America are most susceptible to infection. Younger plants are more attractive to aphids than older ones. To minimize outbreaks, sowing of winter cereals should be delayed until aphid populations decline. Proper sowing date allows the plants to develop when aphid populations are lowest. In addition, seed treatment with insecticides, such as Imidacloprid (for *Schizaphis graminum*) or Thiamethoxam (for *Metopolophium dirhodum*), or both, may contribute to reduce the levels of aphids at early stages of development of the plant (up to 60 days after germination).

Halo Blight

Bacterial blight has been reported from most regions of the world where oats are grown. It is usually not a serious economic threat, but may cause considerable damage under some conditions. The disease poses a greater problem in relatively cool, moist areas, such as the British Isles (Davies, Noble and Norman, 1955), the Highlands of Kenya (Harder and Harris, 1973), on winter oat in Canada (Martens, Seaman and Atkinson, 1985) and in the southeastern USA (Cheng and Roane, 1968), or in some winters in South America (personal observation of the author).

Halo blight of oats is caused by *Pseudomonas coronafaciens* (Elliot) Young, Dye, Wilkie. Lesions occur mainly on leaf blades, but they are also found on stems, coleoptiles and leaf sheaths. Halo blight produces light green, oval spots, the centres of which become water-soaked and darker than the margins. Spots seem to be surrounded by pale green halos. Later, the whole spot, including the halo, turns brown. Spots may coalesce to form an irregular blotch. There are usually little bacterial exudates from the lesions. Exceptionally, if conditions remain particularly favourable, the entire plant may be defoliated, or the bacteria may reach the crown, killing the plants (Martens, Seaman and Atkinson, 1985; Harder and Haber, 1992; Wallwork, 1992).

Bacteria causing halo blight are seedborne and can survive on infected crop residues. The first seedling infections develop from bacteria on the surface of the seeds. From these infections, the bacteria can spread readily from leaf to leaf and from plant to plant during moist spring weather. In late spring, the disease in some fields may look severe, but often a spell of warm, dry weather will check the development of blight and new growth will be relatively free from infection. During the growing season, infection takes place through pores at the tips of the leaves, through stomata distributed over the surface of the leaves, and through

Figure 12.6
Septoria blotch on oats, caused by the fungus Septoria avenae *f.sp.* avenae *(perfect state* Phaeosphaeria [Leptosphaeria] avenaria *f.sp.* avenaria *O.E. Erikss)*

wounds. Rain, wind and insects, particularly aphids, are the agents responsible for disease spread (Martens, Seaman and Atkinson, 1985; Wallwork, 1992).

In most temperate regions, specific measures are not usually necessary as little further spread of bacteria occurs with the advent of higher summer temperatures. In circumstances where the disease may cause economic losses, cultural methods, such as use of clean seed and avoidance of infected oat debris, should reduce disease levels. Resistance to halo blight is effective and simply inherited. Thus, it should not be difficult to breed resistant cultivars (Harder and Haber, 1992; Wallwork, 1992; Martens, Seaman and Atkinson, 1985).

Septoria blotch

Septoria disease of oats is caused by the fungus *Septoria avenae* f.sp. *avenae* (perfect state *Phaeosphaeria* [*Leptosphaeria*] *avenaria* f.sp. *avenaria*). Other common names for the disease are septoria leaf blotch (Figure 12.6), speckled leaf blotch, and septoria black stem. In cool, moist seasons this is one of the most destructive diseases of oats in the northern third of Illinois, USA (Babadoost, 2004).

Up to 93 percent of the leaves and 31 percent of the nodes have been found infected in an Illinois oat field. Almost 20 percent of the leaf area was killed. The black-stem phase of the disease had killed many of the culms above the top joints, causing severe lodging. Statewide yield losses of 15 percent or more have been recorded in the major oat-producing states of the Midwest and Northeast USA and in Canada. In Canada it is usually of minor importance in western Canada, but it can be particularly severe in eastern Quebec and parts of the Maritime Provinces, where cool, humid weather and a long growing season prevail (Martens, Seaman and Atkinson, 1985; Babadoost, 2004). In Australia, yield losses of 30 percent have been recorded due to Septoria blotch (Wallwork, 1992). Generally, the disease is sporadic in its occurrence from season to season and from area to area. Septoria blotch has not yet been recorded in south Brazil.

Septoria fungus is capable of attacking all aboveground portions of the oat

plant at most stages in its development. Under appropriate environmental conditions, characteristic leaf, leaf sheath, culm, glume and kernel infections are produced. Leaf infections and culm breakage reduce yields and cause lodging. Kernel infections reduce milling quality. Infected straw may have reduced feeding value.

The symptoms of the disease are small, dark brown to purple, oval or elongated spots on leaves. These spots grow into larger light or dark brown blotches up to 20 mm in diameter, with surrounding yellow areas that can cover and kill the entire leaf. The infection may spread to leaf sheaths and through them to stems, where greyish brown or shiny black lesions form. Severe infection may cause lodging. Dark brown blotches can also occur on the head and grain. It is possible sometimes to see tiny black specks (fruiting bodies) in the centre of older blotches (Wallwork, 1992).

The causal fungus overwinters in plant refuse and stubble of a previous oat crop. The sexual stage of the fungus develops in the spring on the refuse and stubble, and produces ascospores that infect leaves of the new crop at about the boot stage. As infection spreads and lesions enlarge, the asexual stage of the fungus develops and produces pycnidiospores, which continue the secondary spread of the disease, especially in humid weather. When infection is severe, leaves senesce early and stems became black, weakened and broken. When lodging occurs, seed yield losses may average 25 percent and seed weight and quality are reduced (Martens, Seaman and Atkinson, 1985).

Oat cultivars and selections differ in their resistance to Septoria blotch. According to Babadoost (2004), early-maturing cultivars tend to be most susceptible. Tall, late cultivars are generally more resistant or escape infection. More resistant cultivars should be available in the future. The wild diploid *Avena* species (e.g. *A. brevis*, *A. nudibrevis*, *A. strigosa* and *A. wiestii*) appear to have considerably more resistance than *A. sativa*. These species may serve as sources of resistance to this disease. Reaction to Septoria is a quantitative character and segregating populations can not be separated into clear-cut classes. Septoria reaction is also influenced by differences in the environment. Oat cultivars and selections also differ in their reaction to all phases of the disease – leaves, culms, glumes and kernels. Resistance to one phase, however, tends to be associated with resistance to other phases.

Other, less important diseases

Powdery mildew

On oats, the symptoms of this disease are very similar to the other cereals (Martinelli, 2001). Initially, they appear as colonies of fluffy white to light grey superficial mycelium, on the upper surfaces of the leaf blades. Sheaths and spikes can be affected under favourable conditions. The mycelium darkens to a yellowish grey with age. The undersides of affected leaves have yellowish necrotic spots at infection sites. At this stage, dry powdery conidia are produced in abundance. Late in the season, black spherical fruiting structures (cleistothecia) develop in the mycelial mats. The fungus (*Blumeria graminis* f.sp. *avenae*) is biotrophic and therefore attacks only living cells (Zillinsky, 1983; Martinelli, 1990). The disease is favoured mainly by cold, dry springs. On oats, it has been

considered a disease of minor importance. To control it, the use of resistant cultivars is the best and most effective approach. Chemical seed treatment can be effective (Martinelli, 2001).

Ergot

Ergot is usually considered a disease of rye, but can attack other cereals, including oats, barley, wheat and many grasses. The fungus (*Claviceps purpurea*) only attacks seed-producing organs and generally yield losses are less serious than losses from discounted grain quality. The ergot bodies (sclerotia) that replace the kernels are toxic to humans and animals, and are difficult to remove from harvested grain (Zillinsky, 1983).

Ergot is more prevalent in cool, temperate climates. The prevalence of the disease may be related to the susceptibility of native grasses in these areas. Flowering habits and floral structures may compromise the level of incidence of the disease (Zillinsky, 1983).

Nematode damage

The cereal cyst nematode (CCN; *Heterodera avenae*) has been reported in many countries. Light soils are generally favourable to it, although with continuous cereal cropping it will generally cause economic damage, irrespective of soil type. Distribution of damage within a field is often uneven. Infestation by the cereal cyst nematode results in a stunted, knotted root system. Aerial parts show reduced growth and yellowed leaves. Panicle development is delayed or absent in severe infestations. Moist, cool weather at the time of larval emergence is favourable to the nematode (Araya and Foster, 1992).

The stem nematode, *Ditylenchus dipsaci*, is widespread throughout western and central Europe, North and South America, Australia and North and southern Africa. The nematode invades the foliage and the stem base of cereals, causing a breakdown of the middle lamellae between cells by secreting a pectinase. The nematodes are highly mobile in moist, sandy soil and can spread rapidly from one plant to another. Nematode activity is greatly decreased in well-drained fields (Araya and Foster, 1992).

PERSPECTIVES

In many areas of the world, the importance of the diseases on fodder oats has been neglected by many involved in their production, such as governments, technicians and even farmers. In this sense, the impact of the diseases in those areas has been partially underestimated, mainly because they do not affect a product that is directly consumed by man. Nevertheless, the damage has often been serious. Often farmers' lack of information and precarious technical support has hindered control, or appropriate management, to avoid losses.

Nowadays, most of the information on oat diseases, their biological characteristics, epidemiology and genetics, originates from research on oats destined for the production of grain. Most of the data is, therefore, less appropriate to fodder production since it has different scale levels, different management and a different environment. In the same way, breeding programmes have concentrated on obtaining resistance for diseases of oats destined for production of grain, especially the rusts, with less emphasis on BYDV, *Pyrenophora* leaf blotch and *Septoria*.

Certainly, there is a demand for more detailed information about the impaet of diseases on fodder oats. All aspects of the interaction of the pathogens with oats, particularly in their natural environment, need to be better understood so that efficient control mechanisms can be developed. Therefore, there is now a considerable demand for a search for and transfer of genetic resistance to most of the diseases that occur on oat species used as fodder.

Recently, some oat breeding programmes have realized this need and begun to make selections and crosses aimed at obtaining more adapted, productive and resistant varieties. Although some small steps have been taken, much still needs to be done. With respect to diseases, fodder oats require high levels of resistance and, ideally, should not need fungicidal sprays. Challenges sueh as crown and stem rusts have been difficult to overcome, particularly in favourable environments. Resistance to new and more complex diseases, like scab, will need much more research and investment.

In the authors' opinion, the importance that fodder oats have assumed in the world is unquestionably due to their huge area and economic impact. This fact itself should certainly influence public institutions and funding bodies to allocate resources to decreasing the impact of diseases. Modern molecular and cellular techniques, such as tissue culture and recombinant DNA, offer a promising route to achieving this goal. In this field, progress would be achieved faster were the various activities of government agencies, the private sector and scientific communities to become even more harmonized.

Chapter XIII
Perspectives for fodder oats

The contributors to this book have described fodder oat growing across five continents, with a very wide range of climates, and in farming systems varying from large-scale commercial enterprises to tiny peasant farms. A range of livestock is also involved: cattle, buffaloes, horses and small stock. The chapters indicate that fodder oats remain important in their traditional areas, and it is expanding in the subtropics as new uses are found for the crop.

The past half century has seen a great change in the area and distribution of oats. Fodder oats, however, are still an important crop and have been moving into new areas and uses as farmers modify their production systems and, in developing countries, livestock production becomes more commercially oriented. Most of the contributors to this book indicate that oats are a crop that is mainly used on the farm where grown, either as whole-crop fodder (conserved or not) or as feed grain, and much seed is also produced and used on the farm. These factors probably explain why data on areas grown are often inconsistent. In many places with hot growing seasons, coarse cereals, especially maize, have increased as a fodder at the expense of oats, and in humid, cool, temperate climates, pasture grasses, especially *Lolium* spp., have become very popular. Oats are, however, now being increasingly used in zones and seasons where they have a definite ecological advantage – areas too cool or dry for maize and perennial pasture. A little oats is grown at high altitudes in the tropics. There are two main situations where oats have a great advantage:

- in cold, short growing seasons, either at high latitudes or high altitudes; and
- in warmer subtropical and Mediterranean climates, where they can be grown in winter and provide excellent fodder while allowing double-cropping.

There has been a very considerable increase in oat growing in the subtropics where, previously, oats was a minor crop (they are traditional in the Mediterranean zone), in two main areas.

- In the southern cone of south America vast areas of oats are now being grown as fodder and cover crops during winter.
- In subtropical and temperate Asia, especially in the north of the subcontinent, oats have changed from a minor crop of Government farms to one of the most important winter fodders in an almost entirely smallholder-run agriculture – largely through the introduction of better, multicut, cultivars; attention to seed supply; and strong demand from the dairy industry. The pattern in China seems to be slightly different where "In southern subtropical paddy areas, farmers use fallow paddy field to grow *Lolium multiflorum* … . This farming system has been extended to more than 2 000 000 ha in southern subtropical paddy areas." (Hu and Zhang, 2003). Ryegrass is suited to many of the other countries in the zone, but requires more careful husbandry and can pose problems of seed supply.

Oats are a simple crop to grow, or perhaps their cultivation is similar to that of

wheat and barley, which are major crops in climates suitable for oats; techniques and equipment for wheat also suit oats. Each zone and farming system has adopted the methods that best suit it – from the simplest hand cultivation on small farms in developing countries to up-to-date mechanized systems in areas of large-scale farming. They are an excellent smallholder crop. Seed rates vary from country to country, and fertilizer practice are largely dependent on soils. A less usual method of growing oats, in areas of mild winters, is sod-seeding them into winter-dormant pastures in autumn. Sowing dates are also dependent on the climate, on the cropping pattern when two crops are taken yearly, and when the forage is needed – or when weather is likely to suit haymaking. The place of fodder oats in rotations varies, but in cereal-growing zones they are a useful break crop.

Oats are sometimes mixed with other forages, but mixtures seem to be rarer than pure-stand oats, probably because oat-legume mixtures are often more difficult to manage. The aim of the mixture may be to improve the overall quality of the forage or to prolong the production season. In mixture with scandent legumes such as peas or vetch, oats serve to support the legume and decrease harvesting losses. In North America, spring oats are mixed with winter cereals to give relay production – a silage cut followed by grazing. In Pakistan, oats at low seed rates are an excellent mixture with berseem since the cereal supplies early fodder as well as continuing to produce in the coldest weather, and then the clover takes over as temperatures rise in spring; a case where an oat-legume mixture fits a multicut situation since berseem is noted for its ability to recover after cutting. Oats+berseem is also used in the Mediterranean region.

Wheat, barley, rye and triticale are all used as fodder, but, in general, oats are a superior crop. Barley has an advantage on saline soils and in drought-prone areas, but these are not major fodder-growing situations. Rye is hardy and tolerates poor soils and grazes well. Wheat is used as an emergency winter feed in smallholder situations in Asia but, as the Pakistan chapter shows, oats produce more and better fodder. In mild oceanic climates, Italian ryegrass is a serious competitor, but requires better seedbed preparation and occupies the land much longer; in smallholder situations, ryegrass seed production or supply may present problems.

Grazing is probably a less common form of using fodder oats than cutting for conservation or green feed, but it is nevertheless widespread. Much depends on farm size, management systems, soil and climate. There can be considerable wastage, especially if the land is wet.

Grazing young oats (and other winter-growing cereals) and later harvesting the crop for grain has a long history and was probably commonest in the Mediterranean zone. Now, in addition to the traditional zone, grazing young oats and then growing them on for grain is reported from other areas of mild winters: Australasia, and the milder parts of the USA and South America. Young oats intended for grain should be grazed lightly and before stem elongation. Swath grazing, where oats are mown and windrowed in autumn to be grazed through the snow, is an interesting development in areas with snowy winters.

On small farms in developing countries, cut-and-carry is almost universal for

all fodders; holdings are small and usually unfenced. Cutting causes less damage to the oats than does grazing, so multicut varieties have been taken up enthusiastically by smallholders.

There is general agreement that, in suitable climates, oats are well suited to haymaking, and oat hay is traded in large quantities both within and between countries. The importance of this trade is shown by specialized hay cultivars being developed in Australia for the South-East Asia hay trade. Oats ensile well for on-farm use. Oat straw is a valuable feed resource, more palatable to stock and more nutritious than the straw of wheat or barley; in addition to being used on-farm, it is traded to feed lots in some countries.

Most work on oat diseases has been carried out on oats for grain, with fodder oats relatively neglected despite often serious damage. The disease situation may be becoming potentially more serious as oat areas expand in mild, subtropical climates. The main control will have to be through breeding for disease resistance, allied with careful crop husbandry.

Good cultivars are the basis for crop improvement. Fodder oat varieties have generally been a by-product of breeding for grain, and the few specialized fodder oat breeders are working with modest resources. In most countries, hulled, hexaploid oats are the basis of most forage cultivars; in many cases both *Avena sativa* and *A. byzantina* may be involved in a cultivar's ancestry. *A. strigosa*, which formerly was a minor cereal of poor soils, is now grown on a vast scale in the Southern Cone of South America. Naked oats are not prominent as fodder and, in China, as reported in Chapter VIII, imported hulled cultivars are displacing indigenous naked types in their traditional homeland. Only some countries have fodder oat breeding programmes and, where it is being done, it seems to suffer from underfunding and the general move away from government support for agricultural research. Most oat breeders are mature and there is a scarcity of young breeders coming forward as replacements. Access to improved cultivars and to germplasm may be a problem in some countries: government departments in developing countries can not always afford to purchase rights to registered cultivars. Tightening of quarantine regulations in Australasia may make access to germplasm from outside the zone more difficult.

Since oats are a cereal crop, there are few technical problems in producing seed. Seed supply is not a problem in areas of large-scale farming. In countries where farming, and especially stock-raising, is mainly by smallholders, however, there are often problems in bulking and marketing improved fodders, oats included. Often good, adapted cultivars are available in small quantities on research stations, but the means are lacking to get these bulked to sufficient quantities so that they are available for widespread farm use. The problem is more serious for fodders than for other field crops; fodder seed production is often neglected by government agencies, perhaps more so in countries where fodder is the responsibility of livestock departments. Pakistan tackled this problem in the early 1990s by encouraging the larger farmers and seed companies to handle fodder seeds and by making mother seed of adapted cultivars available to them (Chapter VI, and Bhatti and Khan, 1996); seed supply

Figure 13.1
Sheep on the move in Qinghai, China

Figure 13.2
Oats for winter feed (hay) being grown in a sheep pen, Qinghai, China

Figure 13.3
Oat seed production base, to supply seed for use on the Tibetan-Qinghai Plateau, China

was no longer dependent on departmental budgets and good material has become readily available. In China, oats are widely used as fodder and nowadays transhumant herders on the Tibet-Qinghai plateau (Figure 13.1) are being encouraged to sow oats in the pens (Figure 13.2) where sheep are kept in winter; the thermal growing season in the herding areas is too short for seed production, so a large seed base has been established in lower, agricultural areas. Farms in Qinghai are very small family units but seed production has been organized in one suitable county, with the capacity to produce more than 5000 t of oat seed annually.

The organization of seed production is simple, and a good model. Suitable cultivars are identified through ongoing testing by research institutions, which supply the breeders' seed; a government Grassland Station bulks seed (Figure 13.3) of the recommended cultivars and supplies it to a commercial seed company; the seed company organizes production by contracting farmers; inspection is by the Grassland Station; and marketing is by the company.

Fodder oat production must be part of improving livestock production. In general, the two components are well integrated at farm level but, in the South America studies, the areas growing oats mainly as winter ground cover are distant from stock-rearing zones. In many areas of smallholder farming there is a need for improvement of both the stock and their veterinary cover; increased use of sown fodder means a change from a very low external input system to one where inputs have to be paid for, so stock with greater potential are needed.

SOME CONCLUSIONS

This section does not attempt to summarize all the conclusions that can be drawn from the preceding chapters, but some important conclusions are that:

- fodder oats continue to have an important place in situations where they have an ecological advantage, and should be encouraged for winter grazing in mild climates; in cold zones with short growing seasons; and in climates suitable for making oat hay;
- oats have become a very important cover crop in some systems, but this is not well integrated with livestock production;
- more attention and resources are needed for the development of oat cultivars specifically intended for fodder: grazing, cutting, hay or silage; it is necessary to attract young breeders to fodder oat work and to fund them;
- for smallholders, assuring access to seed of improved cultivars is very important; this involves producing seed of acceptable quality, and marketing it so that it is within easy reach of farmers;
- extension efforts should be intensified, in particular by extension services in countries where the main oat growers are smallholders, to make sure that farmers are aware of new, adapted cultivars, with emphasis on where oats can fit into the cropping and livestock system; provision of livestock services is also necessary, and extension should focus on zones where milk can be readily marketed; and
- there is a need to re-examine the collection of statistics on oat areas since the recent expansion of oats for fodder; for example, vast areas in South America are not being reflected, certainly in FAO statistics.

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This book contains a series of regional studies focusing on oats used as fodder rather than grain. Oats are well adapted to areas of mild winters or cold climates with short growing seasons; their use is also expanding rapidly as a winter soil cover in subtropical South America. Oats have become very popular among small-scale farmers in Pakistan and surrounding areas, for dairy production and as a cash-crop to supply town dairies, and studies by national specialists in the Himalaya-Hindu Kush zone describe their development and use. Oats are easy to grow with equipment and techniques used for wheat. Introduction of multicut varieties has reinforced the popularity of oats as fodder, but continuous breeding efforts are necessary to maintain disease resistance. There are few breeders working on fodder oats, and new, young breeders and funding are needed to maintain the work.

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